ACROSS COUNTRY DAIRY BREEDING STRATEGIES IN SUB-SAHARAN AFRICA

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Declaration

I declare that this thesis is my own composition and that the research described in it is my own work, except where acknowledged. The work described has not been submitted for any other degree or professional qualification.

Oluyinka Opoola

December 2018

"Dedicated to God Almighty in Him I move and have my being"

Lay Summary

Genetic improvement of farmed livestock has had a major impact on productivity, resource use efficiency, and food security, in many temperate countries over the last 70 years. Being permanent, cumulative and usually highly cost effective, genetic improvement is also of huge potential value in countries mostly in need of improved food security, like those in sub-Saharan Africa. However, most smallholder dairy farmers in these countries have not benefited from animal genetic improvement because of inconsistent breeding strategies, poor breeding infrastructure, small herd sizes and lack of performance recording systems. As a consequence, genetic improvement initiatives have mostly relied on importation of exotic breeds. Although when done properly this may underpin dairy production, there is concern that imported stocks are not always suitable and ad-hoc importations may marginalise indigenous genetic resources. With recent improvements in data recording and implementation of organised breeding schemes, together with recent advances in statistical genetics, there is an opportunity to develop new approaches to livestock improvement, suitable for application in sub-Saharan Africa. However, these new approaches need to be investigated and tested. Through the use of a scoping survey and analysis of dairy performance data of Holstein-Friesian and Jersey breeds from Kenya, South Africa and Zimbabwe, this thesis aimed to:

(a) Examine the state of dairy improvement infrastructure with emphasis on the challenges and opportunities under different production systems.

(b) Determine the commonalities in the source of sires used in dairy breeding among different countries.

(c) Estimate genetic parameters based on the performance and pedigree information of cows within and across countries.

(d) Determine the potential genetic gains that could be achieved from selection practiced within and across countries.

Survey respondents identified challenges facing the different production systems and how they can be solved. Across the animal ancestry in seven generations for both studied breeds, family groups performing in the different countries could be traced back to common sires. Running genetic evaluations using pooled data from the three countries led to better genetic progress than using data from individual countries. Individual countries benefited at varying levels from the joint genetic evaluation of production and reproduction traits. A joint across-country genetic improvement programme has the potential to enhance future breeding strategies in sub-Saharan Africa.

Abstract

Genetic improvement of livestock has a major impact on animal productivity and its effects are permanent, cumulative and usually highly cost effective. It is also of considerable potential value in countries, mostly in need of increased food supply and security like those in sub-Saharan Africa. However, genetic improvement has not been carried out systematically in most sub-Saharan Africa countries. This is in part because of lack of animal performance recording, insufficient infrastructure, small herd sizes and limited pedigree information. Most genetic improvement initiatives in dairy cattle have often relied on importation of foreign (exotic) breeds. Only a few countries such as South Africa and Kenya have been collecting dairy performance data for national genetic evaluations for some time. Initiatives such as the African Dairy Genetic Gains Programme are helping other countries such as; Tanzania and Ethiopia to develop animal recording systems which will start to provide pre-requisite data for genetic evaluations.

Improvements in data recording in multiple countries present an opportunity to develop new approaches to dairy improvement and across-country genetic evaluations. Across-country genetic evaluations would facilitate selection decisions and underpin the fledgling breeding programmes in these countries. Elsewhere, pooling and jointly analysing data across different countries, where common sires are been used, has resulted in more accurate genetic evaluations than using within-country data only. The hypothesis in the present study was that across-country genetic evaluation of dairy cattle in sub-Saharan Africa would result in accurate genetic parameters and estimated breeding values hence, improve genetic progress. In order to test this hypothesis, four objectives were addressed as follows. Firstly, a survey was conducted to investigate the current status and needs of the dairy improvement sector in sub-Saharan Africa. Secondly, existing animal data collated from three countries (Kenya, South Africa and Zimbabwe) from Holstein-Friesian and Jersey breeds were used to determine the level of connectedness among the respective dairy populations. Thirdly, estimates of genetic parameters and breeding values for milk production and fertility traits were derived within and across these countries. Fourthly, the potential genetic gains that could arise from within and across-country genetic selection were estimated.

Results from the survey indicated that the main respondent's challenges in sub-Saharan Africa dairy production systems are; poor animal recording, poorly defined animal genetic improvement goals and strategies, inadequate dairy marketing structure and scarce human capacity. The survey identified close collaborations as one of the mitigation measures to these challenges. Results from production and pedigree data for the three countries showed that there were strong links and connectedness in both breeds. Genetic parameter estimation indicated that all three populations would benefit from joint genetic analyses in terms of improved accuracy of estimates. For example, in Holstein-Friesians, heritability (h^2) for 305-day milk yield in five lactations (305D MY) across the three countries was 0.11 (s.e=0.014). Within country, estimates for South Africa and Zimbabwe were 0.12 (s.e=0.018) and 0.10 (s.e=0.025), respectively, whereas it was not significantly different from zero for Kenya. In fact in several cases, within-country parameter estimates were either not significantly different from zero or non-estimable. Genetic parameters were always estimable in across-country analyses.

In terms of expected genetic progress, the results showed that all three countries would benefit from genetic progress generated from selection in an across country initiative. For production traits, Kenya benefited the most (100% increase in genetic gain from across-country compared to within-country selection) than Zimbabwe (55-73% increase over within-country) and lowest benefits for South Africa (2-28%). For reproduction traits, Kenya again benefitted the most (100%), as compared to Zimbabwe (59-100%) and South Africa (16-69%). The study suggests that, in general, joint genetic evaluations may support breeding programmes by providing more accurate genetic parameters and estimated breeding values than national initiatives. Furthermore, an across-country breeding programme based on a joint genetic evaluation could provide a platform for shared genetic progress. Such a programme would offer a wider choice of animals for selection than national evaluations. This type of across-country collaboration would facilitate animal trade between countries in terms of both exportations and importations, and would also address some of the key needs identified in the stakeholder survey.

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List of Abbreviations

305D MY	305-day Milk Yield in Five Lactations
AFC	Age at First Calving
AI	Artificial Insemination
CI	Calving Interval
CI1	Interval between First and Second Calving
CI2	Interval between Second and Third Calving
CFC	Co-ancestry Inbreeding Coefficient
EAZ	East African Zone
ET	Embryo Transfer
First MY	305-day Milk Yield in First Lactation
SSA	sub-Saharan Africa

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Selected Presentations at Conferences

1. Theatre presentation at British Society for Animal Science Conference (BSAS 2016), University of Chester, United Kingdom.

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3. Poster presentation at Centre for Tropical Livestock Genetics and Health Conference (CTLGH 2017), University of Edinburgh, United Kingdom.

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CHAPTER 1

1.0. INTRODUCTION

Livestock are important assets in Africa (Meltzer, 1995; Zaibet *et al.,* 2011). Africa is endowed with a large population of livestock with mainly different indigenous local cattle, goats and sheep (FAOSTAT, 2012), with cattle taking the lead in production level and gross domestic product (Amare *et al.,* 2012). A small population of exotic breeds have been introduced to several countries in Africa to improve the production levels in terms of milk yield of the indigenous breeds (Van Marle-Köster and Webb, 2014). Sub-Saharan African livestock production accounts for 40% of the agricultural GDP mainly through meat, milk, eggs, wool, hides and skins. (FAOSTAT, 2006).

Dairy production and marketing play a crucial role in the livelihoods of over one billion people in Africa, including small-holder livestock farmers (McDermott *et al.,* 2010). Dairy farming in sub-Saharan Africa (SSA) has been shown to contribute positively to the livelihood of the rural populations and therefore, plays a significant role in enhancing rural development, provision of food and improvement in the standard of living for peri-urban households (Zaibet *et al.*, 2011; Kebebe *et al.,* 2017). Methods of dairy production in most African countries comprise; small-scale (small-holder) and large-scale production systems. Small-scale system occurs mainly in farms which combine rearing of a few livestock with crop production. They have small land areas and are found mostly in rural areas (Gollin and Rogerson, 2014). In fact, the bulk of dairy production in sub-Saharan Africa occurs in the small-scale system of farming (Bebe *et al.,* 2003; Mujibi *et al.,* 2014). In the Eastern parts of Africa, small-holder dairying supplies over 80% of milk to the markets (ILRI, 2006; Kurwijila *et al.,* 2001) and offers nutritional security to the rural livelihoods especially in societies with traditional dairy cattle keeping (Migose *et al.,* 2018).

Dairy farming has been the main economic activity for people in the sub-Saharan region, and it will remain tremendously important for the foreseeable future. Dairy breeds include indigenous Zebu and exotic breeds and their crosses. Exotic breeds currently used in Africa include; mainly Holstein-Friesian, Jersey, Ayrshire, Brown-Swiss and Guernsey. Genetic evaluations of these breeds have not been systematically performed. This is due to small herd size, poor performance recording, indigenous dairy genetic resources, limited pedigree information, inadequate breeding input services and supplies, limited human capacity and skilled personnel (Missanjo *et al.,* 2013). Whilst about 95% of the milk produced in sub-Saharan Africa is from high-producing indigenous and crossbred dairy cows mainly raised on poor small-holder farm resources, this study focused on pure Holstein-Friesian and Jersey breeds imported into Kenya, South Africa and Zimbabwe previously used for artificial insemination purposes. This is because the imported breeds into Africa have not been evaluated for their genetic potential within the Africa terrain. The future of a sustainable dairy sector in Africa depends on some importation but mainly on crossbreds and potential indigenous dairy cows. The quest for more knowledge on the African dairy sector is increasing over the recent years. Dairy farming has been envisaged as a means to enhance the nutritional status and source of income of the farmers (Kebebe *et al.,* 2017). Genetics and genetic improvement has been the main hindrance for dairy development in sub-Saharan African countries. In addition, efforts in dairy improvements have been made in some countries such as South Africa, Kenya, Ethiopia, Tanzania, Malawi, Nigeria, Tunisia, Ghana, Zimbabwe, among others with varying degrees of successes and failures.

Although traditionally animal data recording has not been practiced extensively and systematically in sub-Saharan Africa, data have started being collected in some countries such as Kenya, Ethiopia, South Africa, Tanzania and Zimbabwe. Improvements in data recording in multiple countries present an opportunity to develop new approaches to dairy improvement and across-country genetic evaluations. The latter has not been done in Africa, yet. Across-country evaluations would facilitate selection decisions and underpin the fledgling breeding programmes in these countries. Elsewhere, pooling and jointly analysing data across different countries, where common sires are used, has resulted in more accurate genetic evaluations than using within-country data only (VanRaden and Sullivan, 2010). This has led to the implementation of many developmental projects in favour of dairying (Okeyo, 2016). Different trends have been noticed in dairy sectors of different countries over the past years (Ndambi *et al.,* 2007). Therefore, we hypothesise that:

a. Across-country genetic evaluation of dairy cattle in sub-Saharan Africa would result in accurate genetic parameters and estimated breeding values hence, improve genetic progress.

b. Across-country genetic evaluation would yield higher genetic gains/ genetic progress than they would through individual country (national) genetic evaluation.

Through the use of a scoping survey and analysis of animal performance and pedigree data of Holstein-Friesian and Jersey breeds from Kenya, South Africa and Zimbabwe, the present study aimed to:

1. Examine the state of dairy improvement infrastructure with emphasis on the challenges and opportunities under different production systems.
2. Determine the commonalities in the source of sires used in dairy breeding among the different countries.
3. Estimate genetic parameters for milk production and reproduction traits within and across countries.
4. Determine the potential genetic gains that could be achieved from genetic selection of sires within and across countries.

1.1. Thesis outline and main objectives

The overall aims of this PhD thesis were to (i) assess the state of existing data and dairy improvement, (ii) examine the feasibility of within and across-country genetic analysis of Holstein-Friesian and Jersey breeds and (iii) predict future response to selection practiced within and across-country. The thesis is organised in the following chapters:

Chapter 1 presents an introduction to the thesis.

Chapter 2 gives the background and general overview on previous research on dairy improvement of exotic and indigenous breeds currently used for dairy production in sub-Saharan Africa.

Chapter 3 describes the assessment of the current state of dairy improvement infrastructure and capacity in sub-Saharan Africa. This study was carried out using an on-line survey.

Chapter 4 investigates the feasibility of within and across-country genetic evaluations using pooled data of Holstein-Friesian and Jersey cattle from Kenya, South Africa and Zimbabwe.

Chapter 5 predicts the genetic gain and progress that could be derived in Holstein-Friesian and Jersey populations in these three countries from within and across-country genetic selection.

Chapter 6 provides a general discussion of results along with research implications, and relevant conclusions and recommendations.

CHAPTER 2

2.0. BACKGROUND

2.1. Dairy production and cattle management in sub-Saharan Africa

There are over 300 million dairy cows worldwide which provide approximately 60% (620 million tonnes) of the total milk production (FAO, 2017). Milk production in sub-Saharan Africa amounted to 41 million tonnes in 2011, of which three-quarters were produced in East Africa (FAOSTAT, 2014). Cow milk accounted for 80% of all milk produced in sub-Saharan Africa (FAOSTAT, 2014). Sub-Saharan Africa accounts for 2.8% of the world milk production (FAOSTAT, 2000, Otte and Chilonda, 2003). There is a substantial flow of genetic material from large farms and also from abroad to small-holder dairy farms, which produce the majority of milk in the region. Various forms of reproduction technologies are being used to optimise milk yield (Tadesse and Dessie, 2003). At the same time, the use of artificial insemination is practiced in most small-holder farms (Temba, 2011). This gives farmers the opportunity to use a superior bull's semen without having to buy the whole live bull.

A number of attempts to use exotic breeds in Africa have yielded varying results (Tadesse and Dessie, 2003). However, over some time there has been strong interest in the introduction of exotic breeds such as Holstein, Friesian and their crosses. The main driver has been to improve milk yield. A smaller population of other exotic breeds such as the Brown Swiss, Fleckvieh, Jersey and Guernsey among others have also been introduced. Cross-breeding programmes in the various systems of managements have been introduced as an effort to improve milk yield and adaptation in many of the tropical countries (Ehui *et al.,* 1995, Roschinsky *et al.,* 2015, Geshaw *et al.,* 2011, Kahi *et al*., 2000). Previous reports (e.g. Madalena *et al*., 1990, Thorpe *et al*., 1993, Rege *et al*., 1994 and Syrstad, 1996), have shown that the first generation (F_1) cross do very well in terms of production, and are also superior to indigenous breeds. However, the major problem has been on how to proceed after the F_1 population (Syrstad, 1996).

Van Marle-Köster and Webb (2014) suggested that the improvement of the genetic potential of indigenous and cross-bred cattle may increase milk yield if feed production, management skills of farmers and animal health services are improved.

Therefore, it is important that milk yield is improved through genetic assessment of both production and reproduction traits (Otte and Chilonda, 2003). However, it is expected that to obtain the best dairy performance, genetic potential should be above 30% than what the environment can support (Walshe *et al.,* 1991). A previous study by Staal *et al.* (1997) suggested the following types of animals (genotypes) for dairying in different production environments: - high production (over 4,000 kg/yr): pure dairy breed or 75% dairy cross; - medium production (3,000 to 4,000 kg/yr): 50-75% dairy cross or synthetic breed; - low production (1,500 to 3,000 kg/yr): 25-50% dairy cross or synthetic breed (less than 1500 kg/yr) (Staal *et al.,* 1997). A recent study by Muluye *et al*. (2017) showed that cows with exotic levels of 75% best fit the urban production system, medium exotic levels of 50-62.5% fit into the peri-urban production system and low exotic levels of 25-50%, fit the rural system of dairy production. Even though the local breeds are less productive, proper breeding schemes and management will greatly increase milk yields on a more sustainable basis (FAO, 2001; ILRI, 2006). An adequate and sustainable system must rely on the local breeds for within and across-country evaluations.

2.2. Dairy farming systems in sub-Saharan Africa

The main management systems of dairy production practiced in sub-Saharan Africa is the large-scale and the small-scale dairy system of farming. The large-scale is subdivided into; large-scale intensive and large-scale extensive farming. Similarly, the small-scale is subdivided into; small-scale intensive and small-scale extensive farming system. It is estimated that about 80 to 90% of milk in Africa is produced in the small-scale farming system (FAOSTAT, 2017).

2.2.1. Large-scale system

2.2.1.1. Large-scale intensive dairy farming

The large-scale intensive system of dairying is where dairy cattle are completely raised and fed with concentrates, silage, hay and forage solely for the purpose of milk production. The forage can be grown on farm or purchased. This system comprises large farms with more than 30 graded exotic dairy cattle, and few indigenous Zebus and their crosses. The large-scale intensive of dairying is also practiced at varying levels (Ndambi *et al.,* 2007) or in areas where grazing land is scarce. Such farms are usually owned by businessmen or civil servants working and living in the city. They could also be owned by universities, research institutes or non-governmental organisations. The system requires large capital, inputs and infrastructures. This farming system usually has a means of delivering their milk in bulk immediately after milking, enabling them to capture higher milk prices than other systems of farming. They are also seen both as a lucrative economic activity and as an attractive investment option for the savings from off-farm sources. The farming system is practiced by urban and peri-urban farmers. Milk production is on average about 18 to 20 litres/cow/day (Ndambi *et al.,* 2008). Some regions where large-scale intensive system of dairying is practiced include the high potential highland areas of central Kenya with grazing pastures (Bebe *et al.,* 2003). In Tanzania, this system is practiced on the slopes and highland areas of Arusha, Mt Kilimanjaro, and Kagera (Orodho, 2006). In Uganda, large-scale intensive dairying is practiced around Jinja and Kagada (MAAIF, 1993).

2.2.1.2. Large-scale extensive dairy farming

The large-scale extensive dairy farming system comprises farms with over 20 local dairy cattle grazing on natural pastures. In some cases, dairy cattle are guided by a hired herdsman as the animals graze on public or rented land. Less capital and inputs are involved when compared to the intensive system. Animals are fed concentrates and usually supplemented by allowing them to graze on pasture lands during the day and sheltered at night. The dairy farms may be owned by research institutes, non-governmental organisations, universities and/or by rich individuals who want to invest in dairy farming. Milk production is on average of 15 to 18 litres/cow/day (Staal *et al.,* 1997). Since the system produces more milk than the small-scale dairy system of farming, sales are usually done directly to the local milk collection centres.

2.2.2. Small-scale system

2.2.2.1. Small-scale intensive dairy farming

This is also known as the small-holder dairy farming system. Small-holder dairy farming in Africa is classified into rural, peri-urban and urban, dependent on geographical location, and type of breeds and genotypes (Gizaw *et al.,* 2017). Farms usually have 1 to 2 graded milking cows in a herd of about 10 to 16 indigenous and cross-bred cows and calves. The rural systems could also be found in areas such as villages and are mainly composed of low grade cattle, indigenous breeds and a few exotic cross breeds (Tsehay, 2002; Matawork, 2012). The peri-urban and urban systems are found in and around towns and cities. Zero-grazing is commonly practiced in the small-scale intensive system and the household usually owns a small piece of land on which it grows forage (mainly *Pennisetum purpureum*) for the animals and some cash crops mainly for home consumption. Milk yield per cow reaches 8 to 12 litres/day, which is obtained with relatively high use of concentrates. Manure is easily collected from the cows and utilized as fertilizer. Household income from off-farm sources is significant (Otte and Chilonda, 2003).

2.2.2.2. Small-scale extensive dairy farming

Small-scale extensive dairy farming refers to cattle grazing on natural pasture (grassland-based). It consists of small farms of 10 to 40 indigenous dairy cows and a few (25%) improved/cross-breds. The farms usually own little land (about 2 ha), but have access to larger public grazing land. The farmers do not use concentrates, but supplement animal feeding with salt as a source of minerals (Ndambi *et al.,* 2008). Due to the small-scale production and distance from the city and potential market, milk is usually sold to local vendors, who collect milk once a day from several farms. Approximately 50% or more of the farmer’s income is from livestock, and more than 20% of the household food energy is directly derived from either livestock or livestock-related activities (Swift, 1986). In addition, livestock serve as beast of burden and means of transportation, and waste products such as manure are used to fertilize the crops to optimize growth. In Eastern and Southern African countries like Kenya, Ethiopia, Malawi and Zimbabwe (Chakeredza *et al.,* 2007; Oosting *et al.,* 2006), some of these farmers cultivate fodder trees and shrubs to compliment for the feed shortage during extreme climatic conditions such as drought (Franzel *et al*., 2014). At times, the cows may be found in the company of other livestock such as a few chickens, sheep and goats (Staal *et al*., 2001). Average production rate is about 1 to 2 litres/cow/day.

2.3. Challenges facing dairy production in sub-Saharan Africa

The challenges facing livestock production emanate from an increased human population, and the economic development and urbanisation in African countries (Ndambi *et al.,* 2007). The need for dairy products has increased in most developing countries (Bebe *et al.,* 2003) and has led to the simultaneous growth in the need for animal products through an increase in animal population rather than its productivity (Nicholson *et al*., 2001). Otte and Chilonda (2003) showed that the growth in the livestock products in sub-Saharan Africa were not matching the population growth and therefore resulted in a decline in per capita production for meat and milk at -0.6% and -1.0%, respectively for the period 1989-1999. The gap between the demand and supply of livestock and livestock products is growing in developing countries and is largest in sub-Saharan Africa. In the last two decades, per capita output of livestock products has hardly changed. The region's importation of exotic livestock cattle continued to grow and this trend imposes structural constraints to sustained expansion of livestock production (Rege *et al.,* 2011). Irrespective of the dairy farming systems (large-scale and small-holder systems), food animal production is generally affected by inadequate feeding, high disease challenge and poor market organisation that invariably affects the competitiveness of the sector, especially of small-holder livestock producers. This results in a limited commitment to evolve and implement livestock development policies that facilitate institutional changes and provision of innovation platforms for service delivery and uptake of genetic technologies (Ehui *et al.,* 2009). In the coming years, it is expected that there will be a significant rise in demand for improved livestock and livestock products. Studies by Delgado (1999) and Holloway *et al.* (2000) have shown that the demand for milk and milk products is expected to increase by 3.84% by the year 2020. A major increase in the production levels to meet this demand is needed (Scholtz and Theunissen, 2010; Scholtz *et al.,* 2011).

The type of breeding and production system will depend primarily on improving the management system and environmental conditions and identifying the appropriate breeds that would be able to thrive well in African conditions and step up level of production. Enhancing production efficiencies in dairy cattle to meet this demand is a major challenge faced by developing countries (Bondoc *et al*., 1989). Improving the productive performance per cow may be achieved via appropriate breeding strategies (Okeno *et al.,* 2010) as done in developing countries like Kenya and South Africa whereby breeding strategies involve the use of both local selection programmes and imported genetic components (Bebe *et al.,* 2003).

Another challenge is that there is limited applied research-based knowledge about which breeds/genotypes and breeding strategies are best suited for the production systems in most countries in sub-Saharan Africa (Bebe *et al.,* 2003). One of the major limitations has been the lack of availability of adequate data and research capability (Hazell *et al*., 2007). Despite the fact that there has been an increased utilisation of foreign genotypes for breeding in the dairy sector over the years, there has been inadequate genetic information base on evaluating foreign genotypes to the different environments of sub-Saharan Africa. A study that analyses locally collected data on such imported breeds will provide useful results to improve sustainable livestock and dairy production in sub-Saharan Africa.

There is inefficiency in the recording system of animal breeding data in Africa than in the developed countries in relation to animal identification, livestock performance and pedigree information. Several approaches like centralised breeding programmes have been suggested for genetic improvement in some tropical regions (Okeyo, 2016). These were intended to improve livestock breeding so that animals with good genetic potential can be provided. However, these initiatives fail on a long term due to the absence of continuous technical support and livestock farmer participation (Rege *et al.,* 2011). In some countries, there are either no coherent dairy breeding policies or there are outdated ones in place (Bebe *et al.,* 2003). Considering that most of the small-holder farmers are women, there are no policies or government supports on gender equality, access to fair compensation, subsidies and credits along the dairy value chain as compared to men, even though fewer men are involved. There is lack of support services such as access to good breeding studs, heifers, artificial insemination (AI) services, feeds, forages and veterinary services (Hazell *et al.,* 2007). Despite these challenges, some notable progress has been done in some of the sub-Saharan countries through the development of relevant initiatives including; the African Dairy Genetic Gains Programme (Okeyo, 2016), certain national animal recording systems (Kawonga *et al.,* 2012), and the eradication of trans-boundary animal diseases of economic importance (FAO-ECTAD, 2008).

2.4. State of Existing Data in sub-Saharan Africa

In most African countries, there is a lack of animal identification, and pedigree and performance recording systems. A study by Van Marle-Köster and Webb (2014) showed that countries like South Africa, Kenya and Ethiopia have made efforts in implementing a centralised system of within breed recording, selection and crossbreeding for sheep and goat improvement with a varying degree of success. In dairy cattle, compared to other countries in East African Community, Kenya still has a better recording system that was established in 1963 and supported by the government in terms of animal health, artificial insemination (AI) schemes, tick control and livestock extension programmes (Kosgey *et al*., 2011). Since the early 1990s, several organisations have been involved in sustaining the animal recording systems, implementing methods of registration of stud animals (Kenya Stud Book; KSB). The cattle breeders and dairy breed societies form part of the Kenyan Livestock Breeder's Organisation (KLBO) and milk recording is also carried out by Dairy Services in Kenya. All information from KLBO and the dairy services are provided to the Livestock Recording Centre (LRC) for future assessments (Van Marle-Köster and Webb, 2014).

Kosgey *et al.* (2011) reported that despite the availability of organised recording systems, there has been a low participation among small-holder farmers and breeders as they do not immediately see the advantages of participating in the recording schemes. However, dairy cattle production still benefits and has access to a better recording system which is mainly due to the increasing demand for milk and milk product. This has therefore, yielded substantial benefits. There is still potential of obtaining data of animals with high genetic merits for improved production yield. In most countries, data on milk yield are recorded on sheets of papers and archived. In countries like South Africa, milk yield data, genotypes and pedigrees are more organised and data are recorded and stored in computers. Namibia, Ethiopia and South Africa have successfully analysed such data for a number of cattle breeds and small stock breeds (Mostert *et al.,* 2010; Ayalew *et al.,* 2015; Van Marle-Köster *et al.,* 2015).

South Africa developed the National performance schemes for dairy (1917), beef (1959) and small stocks in 1965 (Bergh, 2010) which had a huge impact on genetic improvement of livestock breeds. The BREEDPLAN was implemented with the development of the South African stud book in 2011 for stud breeders. This was done to ensure efficient recording of production data and genetic evaluation of livestock species especially in dairy cattle (Van Marle-Köster and Webb, 2014) through a centralised system known as the Integrated Registration and Genetic Information System (INTERGIS). The aim of INTERGIS is to ensure effectiveness, elimination of duplication, the assurance of data integrity and reliability of the animal recording. Livestock identification and track-back system (LITS) which is a reticular bolus containing a microchip in the middle was developed to trace animal data by animal extension officers in order to collect information even at herd level (Moreki *et al.,* 2011).

The Zimbabwean dairy sector consists of a number of actors from animal health suppliers, milk producers, processors, transporters to service providers. The sector was and remains dominated by production from the large-scale commercial farms and of late by imports. Pedigree and performance data recording in Zimbabwe stopped in year 2000 (Oluyinka communication, 2016). Following the land reform in 2000 and macro-economic policies, milk production plummeted from an all-time annual high of 262 million litres to the current 51 million litres, which falls far short of the estimated demand of 180 million litres. Since 1980, the Dairy Development Programme (DDP) set up 24 smallholder dairy schemes, but majority of the programmes became dysfunctional in 2007/2008 as a result of hyperinflation at farmer and Milk Collection Centre (MCC) level. The main aim of this evaluation was to therefore assess the status of all the MCCs in the country and to develop market based solutions to rebuild the capacities of these MCCs (Kagoro and Chatiza, 2012).

2.5. Dairy breeding and genetic improvement practices in sub-Saharan Africa

Several exotic breeds have been introduced for either pure or cross breeding in sub-Saharan Africa. However, genetic parameters of some of these exotic dairy breeds have only been evaluated in their respective countries of origin (Ayalew *et al.,* 2015). On this basis, the farmers use this information for their cattle breeding designs. Previously, the African dairy farming system used visual knowledge and appraisal, family pedigree and information to assess indigenous highly productive animals for milk production (Bebe *et al.,* 2003). This seemed to have worked for them at the short run without the farmers assessing for undesirable traits that are likely to be transmitted to their offspring (Bebe *et al.,* 2003). Some of these traits (such as poor udder, teat, gait conformation, decreased production performance, long calving intervals and poor body condition score) are hidden and tend to appear when young dairy cows or calves are born (Mpofu and Rege, 2002). Currently, the African dairy farming system makes use of semen for AI purchased from developed countries.

Although, the small-holder dairy farmers depend on AI to improve milk yields in the indigenous breeds (Bebe *et al*., 2003). Importation of Friesian and Holstein semen has been on the constant use to improve and increase the Zebu cattle population (Banga *et al.,* 2007). As the dairy population and semen demand increased, it was realised that importing semen may not be sustainable (Mpofu and Rege, 2002). Traits of economic importance in sub-Saharan Africa include; production traits, reproduction traits and to some extent, milk compositional traits. In the past decade, efforts have been made to improve milk yield at the detriment of fertility traits (Banga *et al.,* 2007). However, current genetic improvement efforts include reproductive traits so as to optimise productivity (Banga *et al.,* 2014a; Makaghlela *et al.,* 2007; Okeyo, 2016). Increasingly, farmer's preference now focuses on dairy cows with optimum milk yield and with high fat and protein for downstream processing. In this study, milk compositional traits were not evaluated across-country because such information was only provided for South Africa data. Therefore, this study focused on milk production and reproduction traits that were common within and across-country for both breeds.

In Kenya, progeny testing schemes for dairy cattle genetic improvement were carried out in the superior local Sahiwal dams and Friesian sire cattle breeds. In 1962, the Kenya National Sahiwal Stud was developed to assess the management systems and the suitability of the indigenous breeds in the semi-arid regions of Kenya (Mpofu and Rege, 2002). The following were evaluated: service sire, cow and calf identification, dates of birth and calving, dates of service and conception, birth and weaning weight, age at 125kg, lactation milk yield, and days in milk. Screening for reproductive performance was carried out in Holstein and Fleckvieh cross-bred heifers but resulted in limited selection intensity as there was poor genetic evaluation to back it up (Muller *et al.,* 2010). Rege and Wakhungu (1992) evaluated genetic and phenotypic trait changes in Sahiwal population using information collected between 1964 and 1988. Lactation yield in the form of 305-day milk yield, calving interval, birth weight and age at 55kg live weight were assessed but showed low genetic progress.

In different countries, embryo transfer (ET) allows dairy farmers to rapidly multiply the genetics of top females in the herd in addition to gaining genetic improvement from purchasing the best semen that is available that comes with using artificial insemination. Embryo transfer is largely being used to step up milk yield in some central and eastern parts of sub-Saharan Africa (Ngongoni *et al.,* 2006). For instance, the rapid detection of onset of heat and synchronisation was carried out by Kugonza *et al.* (2013) in order to determine the suitability of surrogate cross-bred (Ankole x Jersey; Sahiwal x Ankole) dams for embryo transfer following Estrumate® injection. Ankole x Jersey crossbreds gave a shorter mean period between synchronisation and heat (51.0hr) followed by Ankole x Sahiwal crossbreds (61.4hr). The ET status was mildly correlated with the grade of ovary (r = 0.51) and the presence of corpus luteum (r = 0.62).

Chagunda *et al*. (2004) evaluated the effect of selecting Holstein-Friesian cows and sires based on their breeding values for milk yield estimated from their countries of origin on reproductive performance of their daughters on large-scale dairy farms in Malawi. There were low heritability estimates in the gestation interval (GI), calving interval between first (CI1) and second parity (CI2), age at first calving (AFC) and numbers of service per conception (NSC). Most of the reproductive traits were affected by the non-genetic factors of herd, year and season. Phenotypic correlation between NSC and AFC was 0.19, between NSC and GI was -0.05, while that between NSC and CI2 was 0.14. Heritability estimates for GI, NSC, CI1, and AFC; 0.10, 0.04, 0.001, and 0.20, respectively. Therefore, the low heritability estimates for the reproductive traits implies that much improvement is required for adequate management, husbandry practices, and strategically utilising environmental factors.

The life cycle of calving/ lactation in the dairy production systems in SSA varies from those practiced in the temperate regions. In the temperate regions, heifers are inseminated to achieve conception at an average age of 15 months so that they can calve when they are around 24 months (2 years) old. Some farmers aim for a lower puberty age to calving so that heifers calve even before they are 2 years old as they believe this gives greater production rates. This is usually achieved by altering their feeding regime to increase their weight gain thereby inducing early puberty. The gestation period varies between 270 to 283 days and is maintained on an efficient diet during gestation period. The cow usually produces milk upon calving or a day before calving. The cow will then be milked either once, twice or three times a day, depending on the dairy system for about 305 days and dried off from milking for 60 days and put back to calve again. In other instances following calving, cows could be conditioned back in calving within 2 months (60 days) of her giving birth, so that she produces one calf per year. However, many farmers in Africa do not achieve this and cows often give birth every 400 days or more. In SSA, the calving\lactation cycle varies depending on the production systems. Usually, cows tend to calve at a much older age (Makaghlela *et al.,* 2008, Menjo *et al.,* 2009; Muasya *et al.,* 2014) compared to the temperate regions. Causes of longer ages at calving are mainly; poor management systems in terms of feed resources, lack of veterinary input and poor animal husbandry and health resulting in poor growth rates and vitality of heifers. Sometimes, lactation periods could extend longer than the usual period of 305 days in situations where the cows are raised for both commercial and family purposes.

In some western parts of SSA, genetic parameters in dairy traits have been evaluated but not much information is available on evaluation of milk production levels and/or assessments of exotic or indigenous breed components. Genetic parameters and factors affecting the reproductive performance of White Fulani cattle in Southwestern region have been assessed in order to improve dairy herd future performance. For instance, Olawumi and Salako (2010) showed the influence of the sex of calves on birth weight (kg). The male calves had a higher value than female calves with mean values of 24.54±0.51 and 23.19±0.48, respectively. Another study by Malau-Aduli *et al*. (2002) estimated some genetic and phenotypic parameters for dairy traits in Friesian-Bunaji crossbreds and showed that genetic response to selection in Friesian-Bunaji crossbreeds for 305-day milk yield, total lactation yield and lactation length can be moderately high as the proportion of additive genetic variance was fairly high. Repeatability estimates for total lactation yield, lactation length, 305-day milk yield, calving interval and dry period were 0.72±0.06, 0.60±0.10, 0.73±0.02, 0.53±0.24 and 0.56±0.18, respectively. Heritability estimates for total lactation yield, lactation length, 305-day milk yield, calving interval, dry period and age at first calving were 0.44±0.07, 0.52±0.12, 0.30±0.13, 0.18±0.02, 0.26±0.08 and 0.27±0.10, respectively. Also, the correlation coefficient between genetic and phenotypic traits ranged from 0.30 to 0.95. Therefore, improvement programmes for calving interval, age at calving, dry periods and other traits of importance should be based on adequate management practices, given their low heritability estimates.

Genetic parameter estimation work presented in the current thesis is based on data from three sub-Saharan African countries (Kenya, South Africa and Zimbabwe). More details about the dairy cattle breeding in these three countries are provided next. Table 2.1 gives a summary of information from previous studies on breeding techniques and genetic parameter procedures that have been carried out in these three sub-Saharan African countries.

Table 2.1: Summary of Dairy breeding Activities, Data Analyses and Genetic Parameters in three sub-Saharan African countries.

	Zimbabwe	Kenya	South Africa
Artificial Insemination (AI) Services	- AI systems which include national insemination services incorporating progeny testing schemes. Also Exotic semen have been used in both indigenous/ cross bred cattle (Mpofu, 2002)	- AI systems which include national insemination services incorporating progeny testing schemes. Exotic semen have been used in indigenous/ cross bred cattle embarked > 40 years ago (Mpofu and Rege, 2002)	- Biggest user of AI technology and progeny testing. Exotic semen have widely been used in indigenous/ cross bred cattle
Multiple Ovulation Embryonic Transfer (MOET)	- *In-vitro* fertilization, superovulation, embryo recovery, short-term *in vitro* culture of embryos, embryo freezing and embryo transfer - Hormonal assays to test progesterone levels in milk and blood in dairy cows	- *In-vitro* fertilization, superovulation, embryo recovery, short-term *in-vitro* culture of embryos, embryo freezing and embryo transfer	- Hormonal assays to test progesterone levels in milk and blood in dairy cows - *In-vitro* fertilization, superovulation, embryo recovery, short-term *in vitro* culture of embryos, embryo freezing and embryo transfer
Breed Assessment	- Breed assessments of Holstein, Jersey, Ayrshire and Guernsey using best linear unbiased predictions (BLUP) (Missanjo *et al.,* 2013)	- Assessment of gait, digital examination and hoof measurements has been done in randomly selected dairy cows in small-scale farms in Kenya (Gitau *et al.,* 1997). Significant breed	- Inbreeding in South African Jersey breeds (du Toit *et al*., 2012) -assessment of calving interval genetic parameters in Ayrshire, Guernsey, Holstein and Jersey

		differences (P<0.01) in dorsal angle (P=0.03) and dorsal length (P<0.01). Dorsal angle correlated with parity and body condition, while the dorsal length, heel depth and the hoof-base area correlated with the heart girth (P<0.01)	(Mostert *et al*., 2010)
Phenotypic Parameters	- 305 day milk yield assessment using MTDFREML and ASREML	- 305 day milk yield using least square technique of proc GLM in SAS; Assessment of test day yield	- 305 day milk yield using least square technique of proc GLM in SAS, ASReml
Genetic Parameters - Heritability (h^2) -Phenotypic correlation - Genetic correlation	- Milk yield; 0.30, fat yield; 0.32, protein %; 0.33, fat %; 0.42, protein %; 0.44 - Repeatability estimates; 0.39, 0.38, 0.39, 0.49, 0.51, and 0.16, respectively Phenotypic correlation−0.88 - 0.98 Genetic correlation −0.86 - 0.95 (Missanjo *et al.,* 2013)	- h^2 for milk yield in Holstein-Friesian population; 0.17 (Muasya *et al.,* 2014); 0.29, repeatability estimates: 0.34 (Ojango and Pollott, 2001) - h^2 for fertility traits; 0.15 for AFC (Menjo *et al.,* 2009); 0.05 for CI (Ojango and Pollott, 2001)	-Evaluation of production traits and somatic cell in SA Swiss populations (Bouwer *et al.,* 2013) - h^2 = 0.19 for milk, 0.16 for butterfat, and 0.16 for protein yields. Somatic cell score 0.07. - Genetic correlations between the production traits were lowest for milk and butterfat (0.83), and were similar for milk and protein (0.94) and butterfat and protein yields (0.94). These values are

			similar to other South African dairy breeds
Availability of Breeding Stock (s)	- Availability of exotic breeds but have not been genetically accessed in the region	- “Upgrading" indigenous stock and as a service to a limited number of commercial farmers keeping exotic dairy cattle breeds	- High population of exotic and cross breeds with the indigenous breeds which have not yet been genetically accessed
Data Processing	- Done electronically; for laboratory and milk quality. But not accurate enough	- Genetic software package; R package, VCE4, PEST and REML	- Genetic software package, VCE4, PEST and REML
Milk Laboratory Testing	- Butter fat and protein using Bentley 200 infrared milk analyser - Somatic cell count using Counter	- Butter fat and protein using Bentley 200 infrared milk analyser - Somatic cell count using Counter - California mastitis test and milk electrical resistance test	- California milk cell test and milk electrical resistance test (Petzer *et al*., 2013) - Increase in somatic cell count has been shown to be higher in the South African Holstein than the Jersey (Banga *et al*., 2014a). This helps to improve the revenue from the sales of milk produced in the Holstein breed than the Jersey breed

2.5.1. South Africa

Dairy production in South Africa occurs throughout most farms in the Eastern and Northern Free State, North West, the KwaZulu-Natal Midlands, the Eastern and Western Cape, Gauteng and the Southern parts of Mpumalanga. Indigenous South African breeds include Afrikaner, Bonsmara, Drakensberger, Huguenot, Nguni, Sanganer, Tilim, Tswana and Tuli (Gertenbach, 2005; Myburgh *et al*., 2012). At least six exotic dairy breeds of cattle are recognized in South Africa (DAFF, 2012). These are Holstein-Friesian, Jersey, Guernsey, Ayrshire, Swiss (Brown- and Dairy-), and Dairy Shorthorn. Other exotic breeds, such as Red Poll, Simmental, Dexter and South Devon are occasionally seen in the milking parlour. Reports have shown the Holstein-Friesian being the most popular, followed by the Jersey; both have been involved in improving milk yield in the indigenous cattle. South Africa is a member of the International Bull Evaluation Service (InterBull) and participates in international sire comparisons with 4 dairy breeds (Holstein, Jersey, Ayrshire and Guernsey; Mostert *et al.,* 2006). Breeding values, using BLUP methodology, are being estimated for the South African Ayrshire, Holstein, Guernsey, and Jersey breeds, for production traits, udder traits, and linear type traits (Jorjani, 2000). Previous reports have shown that there are 1.4 million dairy cattle in South Africa (Meissner *et al*., 2013). The dairy industry is important to South Africa's job market, with some 4,300 milk producers employing about 60,000 farmworkers and indirectly providing jobs to 40,000 people. Two billion litres of milk production was estimated for the year 2003/04 in South Africa (DAFF, 2012). Despite, these developments and advance changes, majority of the rural or small-holder farmers find it difficult to access these foreign genotypes to improve their local cattle. There is also limited marketing accessibility of milk and milk products and poor accessibility to veterinary and animal health services.

South Africa has one of the most organised dairy production systems in SSA aiming towards improving fertility traits in the dairy sector so as to step up milk yield. Majority of the genetic parameters estimated are for production and fertility traits in the South Africa foreign (exotic) breeds. Various selection programmes have been in place in order to reduce the negative effects that breeding has on production and fertility of dairy cattle. Traits with genetic components such as calving interval (CI) have been assessed in the Ayrshire, Guernsey, Holstein and Jersey breeds in South Africa (Mostert *et al.,* 2010). Heritabilities for CI ranged from 0.01 to 0.07, for the four breeds but highest estimate was for Holstein. A recent study by Bouwer *et al.* (2013) for production traits, somatic cell score and breeding values were estimated in the South African Dairy Swiss. The heritability estimates were 0.19 for milk, 0.16 for protein yields and 0.16 for butterfat. The heritability estimates for somatic cell score was lower (0.07). The genetic correlations between the production traits were lowest for milk and butterfat (0.83), and similar for milk and protein (0.94), while butterfat and protein yields were 0.94. These estimates are similar to previous studies done in other foreign (exotic) dairy breeds prevalent in South Africa (Mosert, 2007). Another report by Makgahlela *et al.* (2007) estimated heritability and genetic correlation for South African Holstein cattle. Estimates were moderate for age at first calving (0.24±0.02) and low for calving interval (0.03±0.01). Genetic correlations between age at first calving and production traits were low to moderately negative, ranging from -0.17±0.07 with second lactation butterfat percentage to -0.50±0.05 with first lactation butterfat yield. The calving interval had moderate to highly positive genetic correlations with production traits, ranging from 0.37±0.10 with second lactation milk yield to be 0.69±0.06 with first lactation milk yield.

2.5.2. Kenya

Kenya has one of the fastest growing small-holder dairy sectors in sub-Saharan Africa. This is dependent on a population of over 3 million dairy cattle of basically high grade *Bos taurus* breeds in conjunction with a relatively successful milk marketing structure (Onono *et al.,* 2013). Previous reports have shown that Kenya has one of the most rapidly increasing dairy sub-sectors in Africa (ILRI, 2000). Cow milk is the most significant agricultural commodity in Kenya and majority of the milk production occurs in the small-holder system (Odero-Waitituh, 2017). The small-holder farmers are found mostly in the high-land areas of Kenya. A variety of production systems are employed by small-holder dairy farmers, ranging from stall-fed, cut-and-carry systems, or supplemented with purchased concentrate feed in areas of high population density where extensive systems are not possible, to free grazing on unimproved natural pasture in the more marginal areas. Exotic dairy breeds tend to be kept in stall-feeding units, while free-grazing dairy animals are more likely to be cross-bred cattle. Kenya milk yield is about 290 to 990 litres per cow annually depending on cows’ genotype (FAOSTAT, 2007). Kenya followed by Ethiopia and Tanzania are among the biggest dairy producers in Africa (Bingi and Tondel, 2015)

In Kenya, predominant dairy exotic breeds and their crosses include Holstein-Friesian, Ayrshire, Guernsey and Jersey breed (Njarui *et al.*, 2012). Indigenous cattle are the *Bos indicus* or the East African Zebu (EAZ) (local Zebu, Boran and Sahiwal breeds). Dairy breeds involved in milk production are the; Friesian, Ayrshire, Guernsey and their exotic crosses or exotic breeds crossed with the local East African Zebu (EAZ). There are about 10 million EAZ which produce a small amount of milk per cow. About 2.5 million of the dairy population is raised on mixed crop-livestock systems with 1 to 4 cattle raised approximately on 1 to 2 hectares of land (Staal *et al.,* 1998). They contribute to approximately 60-70% of Kenyan national dairy output (Omore *et al*., 1999; Kebebe *et al.,* 2017). Bebe *et al.* (2000) showed the Friesian breeds to be higher in population in Kenya among other exotic breeds due to their high production yield in the indigenous cattle. With all these advancements, Kenya is still faced with challenges that deter milk production. Milk production in Kenya is generally found to be as low as 3% of the 18% global production by sub-Saharan Africa (Odero-Waitituh, 2017). This is due to the low productivity of the indigenous breeds than in the exotic breeds. Also, their operations are mainly on low inputs and production per dairy animal is quite low. The Food and Agriculture Organisation (FAO) statistics of 2005 (FAO, 2005) shows that the annual milk growth rate in Kenya continues to lag behind the projected consumption and population growth rates. Despite the large Kenya land mass, 60% of the total milk yield is produced from less than 10% of the country's land mass in the central districts of Kenya where 80% of exotic and cross bred dairy cattle are found. Kenya small-holder farmers do not have or maintain farm records; there is low milk production of 5 to 8 kg/day due to under-nutrition (Omore *et al.,* 1996; Staal *et al*., 1998) resulting from seasonality in quality and quantity of feed resources, as not much of Kenya land area is used despite the large land mass available (Majiwa *et al*., 2012). Increasing sub-division of land aggravates this shortage.

Kenyan small-holder farmers depend on AI services or communal bulls especially where public transport or private AI services are not easily accessed. Only a few farmers raise bulls for breeding on their farm as it's rather expensive to raise them when compared to dairy cows. Therefore, they would prefer to use their limited fodder/crop supplies for cows and female replacements. Other challenges include tick borne diseases such as East coast fever, babesiosis and anaplasmosis (Okuthe and Buyu, 2006; Gachohi *et al*., 2012), fly-borne diseases; Rift valley fever, Trypanosomosis (Thumbi *et al.,* 2010), bacterial infections; Contagious bovine pleuro pneumonia, Brucellosis (Onono *et al.,* 2013), and adverse environmental conditions (warmer climates and lower altitudes; Maloo *et al.,* 1994). All these challenges affect dairy production especially in the small-holder farms as they are raised via extensive farming methods. Nevertheless, dairying in Kenya is regarded as the main source of income and cash flow to the small-holder farmers. Certain strategies have been implemented in order to decrease the limited feed supply such as fodder cultivation on road sides, reliance of farmers on fodder markets and the feeding of cows with crop by-products (Omore *et al*., 1999). In order to meet market demand for milk from an expanding and increasingly urbanised population, the National Dairy Development Project (NDDP), under the Kenya Ministry of Agriculture, Livestock Development and Marketing, has been promoting intensive, stall-feeding units for more than a decade. Farmers are encouraged to grow Napier grass (*Pennisetum purpureum*), establish a stall-feeding unit and develop a farm budget. Where appropriate, farmers are being assisted in approaching the Agricultural Finance Corporation for loans to buy pure- or cross-bred in-calf dairy heifers (NDDP, 1993). Regular visits from specialised dairy extension workers reinforce extension messages to assist farmers in the management of the enterprise (Kenya Ministry of Agriculture, 1993). In the high-potential areas only 10% of the agricultural land remains under natural pasture, compared with 50% in medium-potential areas, which implies that there is limited room for expanding agriculture in the high-potential zone (Reynolds *et al.,* 1996).

The impact of development agencies on Kenya small-holder dairying promises an avenue to alleviate poverty, improve milk production, adequate infrastructure and enhance the effective utilization of intensified land use. It is expected that the population of small-holder farmers will increase in the future if they are assisted appropriately. Therefore, there is an urgent need to expand input services, improve efficient marketing of dairy products and the provision of innovative research supports for these farmers. In other words, the constant supply of inputs services is an urgent priority for improved milk productivity of small-holder dairy farms in Kenya.

Dairy cattle production in Kenya has gradually been growing into a productive agricultural sector. A study by Amimo *et al*. (2006) in Ayrshire identified the significant genetic and non-genetic effects on milk production for farm management and estimated genetic and phenotypic parameters for milk traits based on 305-day milk yield (305D MY). The data analyses identified significant sources of variation by herd, parity and year of calving on 305D MY. The high variation as indicated by both large standard errors and low heritabilities of the milk trait indicate that much improvement in this trait could be achieved through improved data recording and herd management. A high negative annual genetic change in milk yield was observed which was largely due to ineffective breeding strategies both in the herd and national level (Amimo *et al.,* 2006). Menjo *et al*. (2009) evaluated the use of imported semen on survival to age at first calving and AFC for Holstein-Friesian cows in four dairy farms in Kenya. Heritability estimate obtained for age at first calving was 0.15±0.06 with an average age of 1058 days. Cows sired by New Zealand and Australian born bulls calved the earliest (907 days) while unfavourable effects were evident for cows sired by Kenya born (indigenous) bulls.

2.5.3. Zimbabwe

There are both rural small-holder farms and large commercial dairy farms. Predominant dairy breed in Zimbabwe is the Holstein-Friesian, followed by Guernsey, Jersey, Ayrshire, Redpoll, Simmental and Red Dane. The indigenous breed predominantly used or crossed with the exotic breeds is the small, hardy Sanga type. The strains include the Mashona, Nkone and Tuli breeds, which, although renowned for their fecundity, are poor in milk production. Average daily production per cow has remained relatively low as compared to the production levels of the large-scale farmers (Hale, 2001). The milk production levels of various types of cattle under rural conditions include; about 1 to 3 litres/day (150 lactation days) for indigenous breeds; 4 to 10 litres/day (240 lactation days) for crossbreds; and purebred exotic cows, producing more than 10 litres/day (300 lactation days) (Hale, 2001). Dairy animals are fed majorly on maize and its by-products, oats, midmar rye and lucerne (*Medicago sativa*) for as energy and carbohydrate sources and soya beans and cotton seed cake for protein. The major sources of roughage are natural grass, standing (range) hay and maize silage. The Zimbabwean government has made efforts in encouraging the small-scale sector to play a major role in milk production since after their independence in 1980. This led to the setting up of the Peasant Sector Development Programme (PSDP) within the Dairy Marketing Board (DMB), now known as the Dairy Development Programme (DDP) (Dairy Development Programme, 1988; Hale, 2001). This Programme is now under the auspices of the Agricultural Development Authority (ADA) and takes the responsibility for the implementation of dairy development projects in the communal, resettlement and small-scale farming areas in the country (Dairy Marketing Board, 1988). The intention of the DDP is to develop the small-holder dairy farmers so as to improve the level of milk production and to encourage farmers to grow fodder, tree legumes, herbaceous crops and the use of commercial protein sources as supplements to the available crop residues and native pastures for improved dairy productivity (Hove *et al.,* 2003). Zimbabwe currently operates nine dairy schemes and projects spread over five provinces (Hahlani and Garwi, 2014). The small-holder dairy sector in Zimbabwe has over the years grown to a membership of 2000, out of which 800 members produce and sell milk. The Livestock Production Programme (LLP) was developed and supported by Latin America to step up dairy production. LLP helps to provide subsided forage feeds, improve milk processing and its shelf life in a small proactive way for increased market value. Zimbabwean dairy production is still faced with various challenges despite efforts being made to improve milk production (Hahlani and Garwi, 2014). Most of these challenges are encountered by the small-holder farmers. Despite the government's intense efforts in order to improve small-holder dairy farming, majority of the dairy farms still produce at a subsistence level. Other challenges include; inadequate availability of good quality fodder crops, scarcity of genotypes (especially crossbreds) which slows down milk production rates in the small-scale dairy sector, diseases such as mastitis (Katsande *et al.,* 2013), feed scarcity/inadequate feed resources, poor infrastructure and inputs, poor availability of labour, poor marketing of milk, poor milk production and poor recording systems.

Makuza and McDaniel (1997) estimated genetic parameters for milk yield, 3.5% fat corrected milk yield, fat yield and fat percentage in Zimbabwean Holsteins. Heritabilities and repeatabilities for milk yield (0.35 and 0.35), fat corrected milk yield (0.25 and 0.44) and fat yield (0.22 and 0.44) were within the value range for temperate areas, but those for fat percentage were lower (0.20 and 0.50). Age at calving followed patterns similar to those of temperate areas (24 months). Missanjo *et al.* (2013) estimated genetic and phenotypic parameters for somatic cell count (SCC) and production traits for Jersey dairy cattle in Zimbabwe. Heritability estimates for milk yield, fat yield, protein yield, fat percentage, protein percentage, and Log10SCC were 0.30, 0.32, 0.33, 0.42, 0.44, and 0.08, respectively. The corresponding repeatability estimates were 0.39, 0.38, 0.39, 0.49, 0.51, and 0.16, respectively. The phenotypic and genetic correlations between different production traits ranged from −0.88 to 0.98 and −0.86 to 0.95, respectively. The genetic and phenotypic correlations between production traits and SCC were weak and almost non-significantly differently from zero. A similar study was conducted by Nyamushamba *et al.* (2014) in Zimbabwean Jersey and Red Dane cattle. The month of calving, calving interval, parity and quadratic effects of age at calving were fitted and which significantly ($P < 0.0001$) affected the milk, fat and protein yields. Milk, fat and protein yields obtained increased with an increase in calving interval. There was a linear and quadratic relationship between the production (milk) traits and age at calving of the Jersey cattle which implied that milk, protein, and fat yields increased with age of the animal. Therefore, it is important to account for environmental factors when determining genetic evaluations of production traits in sub-Saharan dairy cattle.

2.6. Across-Country Evaluations

The very foundation of genetic improvement relies on the availability of variability and suitable animal data. To determine the level of variability that is used in genetic improvement programmes, performance records provide the useful data. While data in one country may be limited, the ability to pull data across countries implies that bulls or sires can be evaluated more accurately so as to determine which indigenous or exotic cross-breeds and their genotypes would adapt to the tropical terrain and produce more milk in sub-Saharan Africa. This has been the very foundation of the successful international breeding in several developed countries. Hence, InterBull was established (David *et al.,* 2010; Sullivan, 2013). InterBull helps in the global assessment of the genetic merit of bulls whose daughters are located in these countries (David *et al.,* 2010; Sullivan, 2013). Genotype-by-environment interactions are accounted for in across-country genetic evaluations delivered by InterBull. Genotype-by-environment interaction has had significant effects on genetic parameter estimates (Ojango and Pollott, 2005) derived in SSA.

The potential benefit of across-country evaluation of dairy cattle in developed countries for production and reproduction traits has been well documented (Banos and Smith, 1991; Lohuis and Dekkers, 1998; Zwald *et al.*, 2003; Lidauer *et al.,* 2015). Genetic evaluations of dairy bulls from multiple countries allow the potential use of best sires for national genetic improvement strategies. Across country evaluation helps in improving overall genetic response, thereby minimising negative effects from genetic variation, inbreeding and inbreeding depression (Banos and Smith, 1991; Lohuis and Dekkers, 1998; Philippe and De Bretagne, 2013). However, across-country genetic evaluations of dairy cattle raised in Africa have not been addressed before. It is proposed that across-country genetic evaluations could aid in optimising future breeding goals in multiple countries in SSA. Therefore, the data pooled across three countries (Kenya, South Africa and Zimbabwe) used in the current study provides an initial platform to examine possibilities of joint data analysis in production and reproductive traits which could later be extended to other economically important traits. Data were analysed using relevant software for data editing; R package and genetic software such as ASReml®, CFC Inbreeding®, and Fortran-based programs (RelaX®, R Tools®, among others). This gave an understanding of phenotype data in terms of the number of cows in the herd, average milk yield per cow, average amount of milk yield per cow lactation, and among others. Assessment of the pedigree helped in understanding and determining the family structure and genetic links for exotic sires and dams that were common across the ancestry. The expected genetic gain obtained from the PhD findings will be useful in designing future breeding strategies for both production and reproduction traits that could be sustainable in sub-Saharan Africa.

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CHAPTER 3

3.0. Current state of dairying and its potential constraints in sub-Saharan Africa

3.1. INTRODUCTION

The rural economy in sub-Saharan Africa (SSA) is mainly based on agriculture (IMF, 2012; FAO, 2015). In 2014, agriculture in SSA (excluding the Republic of South Africa) employed 62% of the population and generated 27% of the gross domestic product (Alliance for a Green Revolution in Africa, 2014). The agricultural production systems are largely 80% based on small-holder farmers (approximately 2 hectares of land) and contribute up to 90% of the agricultural produce (Wiggins, 2009; 2010). There are 59 million dairy cattle in SSA (FAOSTAT, 2015). Cow's milk accounts for 80% of total milk (FAOSTAT, 2016), of which half is produced in Eastern Africa, followed by Central and Southern Africa while Western Africa produces the least amount of milk (FAOSTAT, 2016). The global demand for animal-derived products is increasing by more than 2% per annum (Yáñez-Ruiz and Martín-García, 2016). In 2011, statistics showed that 41.6 million tonnes of milk was produced implying a 4.9% growth per annum between 1992 and 2010 (FAOSTAT, 2012; 2014). The Holstein-Friesian, used as either a pure breed or as a cross with indigenous breeds, is the main exotic dairy breed used for milk production in SSA. Other breeds such as Jersey, Guernsey, Brown-Swiss, Fleckvieh and Ayrshire are also used.

Since the implementation of genetic selection principles to livestock production, there has been tremendous improvement in desirable quantitative traits in many developed countries. This has led to improvement and availability of milk, meat, eggs and other animal products in these countries (Delgado, 2005). Over time, genetic improvement has been stable in the developed countries with fewer changes that could be sustainable for future livestock and the growing human population. However, genetic improvement has not been widely implemented in SSA. This is largely due to lack of well defined breeding goals and strategies, limited pedigree and performance data recording, poor human capacity and inadequate dairy management practices (Livingston *et al.,* 2011; Missanjo, 2010). Recent initiatives and improvement methods currently in SSA may provide opportunities for efficient animal data recording and implementation of organised breeding schemes.

Also, with recent advances in statistical genetics, there is an opportunity to develop new approaches to livestock improvement, potentially suitable for application in sub-Saharan Africa.

Despite the influx of exotic high-producing breeds into Africa, the dairy sector is still faced with huge productivity gaps (Ojango *et al.,* 2017). In order to contribute towards bridging these productivity gaps, there is need for better understanding of the situation not only from farmers but also the experts that work with the farmers. The current study, therefore, was conducted as a survey targeted towards the livestock experts working in different regions of SSA as the respondents. The hypothesis of the study was that the state of existing animal recording, dairy improvement methods and key issues facing dairy production together with means of addressing these issues are the same across the countries and regions in sub-Saharan Africa. Therefore, the objectives were to (i) determine the current status of animal recording, dairy improvement infrastructure, milk production systems and human capacity in different countries and regions of SSA, (ii) assess key strategic issues in the dairy sector in SSA and (iii) determine the perceived solutions to these issues in different countries and regions of SSA.

3.2. MATERIALS AND METHODS

A survey was carried out using an online questionnaire. Questionnaire recipients were participants of different scientific conferences and workshops related to dairying and genetics that had taken place in Africa. The conferences and workshops were randomly selected from events held over a 15-year period (2000 and 2015). A total of 496 recipients' names on the delegates' lists were contacted as respondents irrespective of their country of origin and residence in Africa. The delegates were predominantly trained scientists and professionals working with farmers. They described themselves in the following categories; animal scientists, livestock extension workers, animal nutritionists, geneticists, animal husbandry workers, researchers and animal breeders.

The questionnaire was implemented using Snap WebHost® software and sent to the recipients via email. The e-survey was active for a period of 90 days after which no further responses were accepted. A reminder e-mail was sent automatically every 28 days upon first receipt. The main themes for survey questions covered are presented in Appendix 1. The themes included the following: breeds and genotypes in use, dairy policies, breeding strategies, data recording systems, livestock improvement infrastructure, human capacity, dairy production challenges, current levels of production and fertility, and genetic evaluation methods. The survey had 22 questions (Appendix 2) which were categorised as open-ended, closed-ended, structured and unstructured questions.

3.2.1. Data Analysis

Survey data were analysed by country and regions with the latter defined as Eastern Africa, Southern Africa and Western Africa (Appendix 3). The survey data were analysed using descriptive statistics that included means, percentages and frequencies of which contingency tables and crosstabs of variables were generated. Analysis of variance (ANOVA) based on a linear model was used to determine significant differences and variations in current dairy status levels between countries and regions ($P<0.05$). Marginal means and standard errors were estimated for each of the current dairy statuses in the three regions specified. The R software package (R Core Team, 2013) was used for the analysis.

3.2.2. Analysis of Variance (ANOVA)

A one-way analysis of variance was used to test differences between variables/ groups in respondent's countries and the three regions in Africa. Hypothesis is given as thus;

- Null hypothesis (H_0) = status of animal recording, dairy improvement methods, dairy production issues and methods to alleviate these strategic issues were the same across-country and region.
- Alternative hypothesis (H_A) = status of animal recording, dairy improvement methods, dairy production issues and methods to alleviate these strategic issues were not the same across-country and region.

3.2.3. Linear Model

The linear model that was implemented to test the hypothesis was;

$$\boldsymbol{Y} = \boldsymbol{X\beta} + \boldsymbol{e} \qquad [1]$$

Where,

$\boldsymbol{Y}$ = Dependent variable (current dairy status variable)

$\boldsymbol{X\beta}$ = Independent variable (region/ country as fixed effect; 3 or 15 levels respectively)

$\boldsymbol{e}$ = Error term

3.2.4. Paired Student *t*-test

A student *t*-test was used to determine pairwise comparison of across-country existing dairy statuses with the t statistic computed;

$$\boldsymbol{t} = \frac{\boldsymbol{M_1} - \boldsymbol{M_2}}{\sqrt{(\boldsymbol{SE_1})^2 + (\boldsymbol{SE_2})^2}} \qquad [2]$$

$\boldsymbol{t}$ = Test statistic for differences between group means

$\boldsymbol{M_1}$ = Group means for existing dairy status in region 1/ country 1

$\boldsymbol{M_2}$ = Group means for existing dairy status in region 2/ country 2

$\boldsymbol{SE_1}$ = Standard error for group means for existing dairy status in region 1/ country 1

$\boldsymbol{SE_2}$ = Standard error for group means for existing dairy status in region 2/ country 2

3.3. RESULT

3.3.0. Edited information from survey respondents associated with dairy production and land tenure systems in sub-Saharan Africa

A total of 70 responses were obtained from 15 countries: Burkina Faso (BF), Burundi (BR), Cameroon (CA), Ethiopia (ET), Gambia (GA), Ivory Coast (IC), Kenya (KE), Malawi (ML), Nigeria (NG), Senegal (SE), South Africa (SA), Sudan (SU), Tanzania (TZ), Uganda (UG), and Zimbabwe (ZW) as shown in Table 3.1. Dairy production was predominantly practiced by small-holder farmers who use the following land tenure systems for dairy production: public ownership, group ownership, lease-hold, family-hold and free-hold tenure systems. Mixed crop-livestock system was one of the major farming systems in which dairy production is practiced. This was because crop residues were used to feed the cattle and harvest from crops also to meet the needs of the farmers and their families. The respondents identified that dairying in SSA was practiced mainly in mixed crop-livestock production systems. Several land tenure systems for dairy production in which respondents were associated with included; lease-hold, communal, private, public, and group ownership.

Table 3.1: Distribution of survey responses by country, gender, occupation, land tenure system and dairy production system.

Country	No of respondents	Gender		Occupation	Land tenure systems	Dairy production system
		F	M			
BF	2	0	2	Government researcher	Not stated	Pastoral farming, mixed crop-livestock farming and subsistence farming
BR	2	0	2	Government extension officer	Private ownership	Mixed crop-livestock farming, subsistence farming, intensive farming (zero-grazing) and zero-grazing
CA	3	1	2	Government (One researcher and Two lecturers)	Private or group ownership	Mixed crop-livestock farming and pasture-based farming
ET	3	0	3	Government researcher	Communal and public ownership	Mixed-crop livestock farming, pastoral farming and subsistence farming
GA	2	0	2	Non-governmental organisation researcher	Private ownership	Mixed crop-livestock farming
IC	3	0	3	Government (Two researchers and One lecturer)	Private ownership, group ownership, lease hold and communal	Subsistence farming, pastoral farming, pasture-based farming and mixed crop-livestock farming

KE	19	2	17	Six extension officers, Four researchers, Four university lecturers and Five non-governmental staff	Private ownership and lease hold	Mixed crop-livestock system, subsistence farming, intensive farming, zero grazing, pastoral farming, and pasture-based farming. Some of the farming systems may be in conjunction with aqua culture, village poultry, and apiculture
ML	3	1	2	One researcher, Two university lecturers	Communal and private ownership	Mixed crop-livestock farming and intensive (zero-grazing) in conjunction with dairy goats and poultry farming
NG	13	1	12	Four university lecturers, Six university researchers, Three student researchers	Communal, private, public or lease hold	Mixed crop-livestock farming, pasture-based farming, subsistence farming, pastoral farming and intensive (zero grazing) farming
SE	2	1	1	One university lecturer, One government researcher	Communal, private and public ownership	Mixed crop-livestock farming, zero grazing, pastoral farming and pasture-based farming
SA	6	1	5	Four government researchers,	Private and communal	Mixed crop-livestock, intensive (zero-grazing), pasture-based and mixed crop-livestock farming systems

				Two university lecturers		
SU	2	0	2	Government researcher	Lease hold	Zero grazing and pasture-based farming
TZ	6	0	6	Five government workers, One extension officer	Communal, private and public ownership	Mixed crop-livestock farming, subsistence farming, intensive (zero grazing) and pasture-based farming
UG	2	0	2	University lecturer	Private	Pastoral farming, mixed crop-livestock farming, intensive farming (zero grazing) and pasture-based farming
ZW	2	0	2	Government researcher	Communal, private, lease hold, or public ownership	Mixed crop-livestock farming and subsistence farming

n = 70 respondents; Country Codes: BF (Burkina Faso), BR (Burundi); CA (Cameroon); ET (Ethiopia); GA (Gambia); IC (Ivory Coast); KE (Kenya); ML (Malawi); NG (Nigeria); SE (Senegal); SA (South Africa); SU (Sudan); TZ (Tanzania); UG (Uganda); ZW (Zimbabwe).

The majority of the respondents were from KE, NG and TZ. The respondents comprised more of males (90%) than females (10%) involved in various occupations. They were associated with different farming systems and land tenure systems in which dairy production is practiced. BR, BF, GA, SU and SE had the lowest numbers of respondents. The main land tenure system that respondents were associated with included: communal, private and/or group ownership. Most of the respondents associated with the land tenure system and dairy production worked with the government as researchers and extension officers.

3.3.1. Current status of dairy production in sub-Saharan Africa

Table 3.2 summarises the current dairy production status across country. On average, 79% of milk produced per country was consumed as liquid or fresh milk. The amount of milk sold in informal markets was higher (60%) than that sold in formal markets (40%).

Table 3.2: Reported current status of dairy production in sub-Saharan Africa.

Categories for status of existing data	Average	Standard deviation	Coefficient of Variation (%)
Number of exotic breeds	2.8	1.66	59
Number of indigenous breed	2.2	1.52	69
Milk consumed as liquid (%)	79.0	26.01	33
Milk processed (%)	21.0	12.36	53
Milk sold in formal markets (%)	40.0	21.13	53
Milk sold in informal markets (%)	60.0	23.24	39
Number of dairy production systems	4.3	3.85	89
Number of land tenure/ownership systems	2.1	1.32	63

The number of production systems in which dairy production is practiced exhibited the highest variation. Lowest variation was in the proportion of milk consumed as liquid (mean = 79%; CV = 33%). Three exotic breeds (i.e. Holstein-Friesian, Jersey and Ayrshire) and 2 indigenous breeds (i.e. Zebu breeds and their crosses to other exotic and indigenous breeds) were used for milk production at different levels of cross breeding.

3.3.1.1. Existing human capacity in sub-Saharan Africa

When the respondents were grouped by country, professional researchers, university lecturers and government extension officers accounted for 29% of the respondents each, while another 10% worked with non-governmental parastatal organisations. The smallest proportion was student researchers (3%). Figure 3.1 shows the existing capacity of respondent's occupation and their involvement in dairy practices in 15 countries in sub-Saharan Africa.

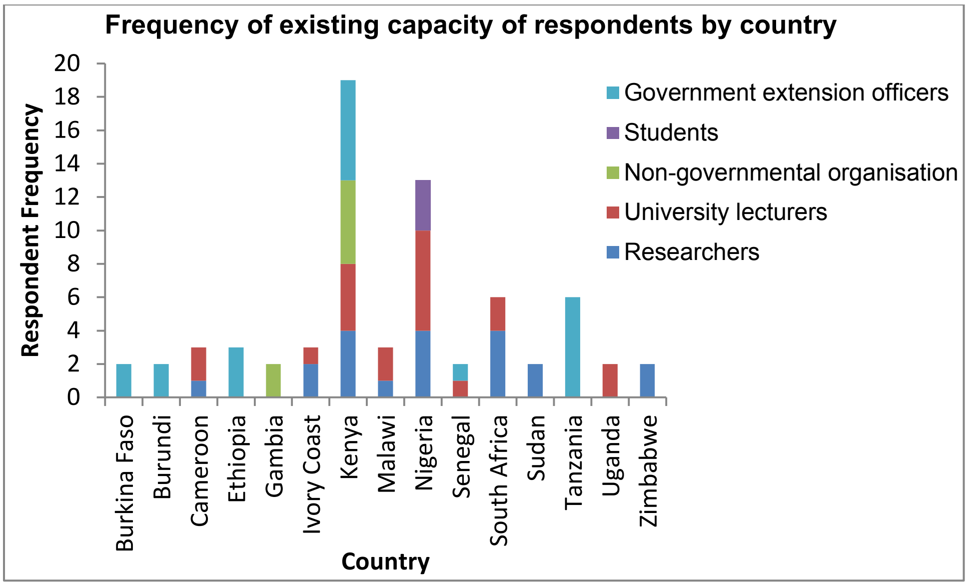

Figure 3.1: Existing capacity of respondents by country.

Respondents were self-identified and researchers defined as those working with mostly research institutes, and private companies, or as consultants. Lecturers were defined as those working in universities and higher education institutes. Government workers were defined as those working with extension services such as animal husbandry. Students were defined as those undergoing training in universities in the field of animal science, genetics and veterinary medicine. NG, KE and SA had the highest numbers of human capacity represented as researchers, lecturers and non-governmental workers than the other countries.

Across all the regions, Eastern Africa had the highest capacity (48.6%) followed by Western Africa (35.7%) then Southern Africa (15.7%). Among the East African countries, Kenya had the most response rate (27%). In West Africa, Nigeria had the highest response rate (~19%) while in Southern Africa, South Africa had the highest response rate (~9%). Among the participating countries Nigeria, Kenya and South Africa had higher numbers of researchers, lecturers and non-governmental workers. Across the three regions, proportion of human capacity working as professional researchers, university lecturers, and government extension officers were 28.6% each followed by 10% as non-governmental organisations and the lowest as student researchers (4.4%).

In addition, there were more respondents in the Eastern region, than the Western region and the lowest in the Southern African region. Of the 70 responses, response rate was highest in KE (19 individuals) than the other countries. Among the East African countries, KE (27%) had the most response rate. In West Africa, NG (~19%) had the highest response rate while in Southern Africa; SA had the highest response rate (~9%). Table 3.3 shows response rates within country and across regions.

Table 3.3: Survey response rate by country and region.

Country	Number of respondents	Region	Response rate (%)
BF	2	Western	2.9
BR	2	Eastern	2.9
CA	3	Western	4.3
ET	3	Eastern	4.3
GA	2	Western	2.9
IC	3	Western	4.3
KE	19	Eastern	27.1
ML	3	Southern	4.3
NI	13	Western	18.6
SE	2	Western	2.9
SA	6	Southern	8.6
SU	2	Eastern	2.9
TZ	6	Eastern	8.6
UG	2	Eastern	2.9
ZW	2	Southern	2.9

n= 15 countries; 3 regions; Country Codes: BF (Burkina Faso), BR (Burundi); CA (Cameroon); ET (Ethiopia); GA (Gambia); IC (Ivory Coast); KE (Kenya); ML (Malawi); NG (Nigeria); SE (Senegal); SA (South Africa); SU (Sudan); TZ (Tanzania); UG (Uganda); ZW (Zimbabwe).

3.3.1.2. Predominant dairy breeds and dairy production systems in sub-Saharan Africa

Respondents identified the breeds used in dairy production and the production systems associated with these breeds in the 15 countries. The breeds were mainly Holstein-Friesian, Jersey, Brown-Swiss, Sahiwal, Zebu breeds (such as White Fulani, Nguni, Tuli, and among others) and their crosses at various levels. Table 3.4 summarises results within country.

Table 3.4: Predominant breeds and dairy production systems by country.

Country	Dairy Breeds/ Crosses	Farming system used in dairy production
BF	Holstein-Friesian, Montebeliarde and Zebu	Not stated
BR	Holstein-Friesian, Sahiwal and their crosses at different levels	Mixed crop-livestock farming, subsistence farming, intensive farming (zero-grazing)
CA	Holstein-Friesian, Red Bororo, White Fulani, Gudali and their crosses at different levels	Zero-grazing, back-yard farming, nomadic farming and mixed crop-livestock farming
ET	Holstein-Friesian, Jersey and Zebu	Mixed crop-livestock system and pastoral farming
GA	Holstein-Friesian, Jersey, Montebeliarde and N' Dama,	Subsistence farming and mixed crop-livestock system
IC	Abondance, Montebeliarde, Holstein-Friesian, N'Dama, Baoule, Peulh Zebu (from Burkina Faso and Mali) and their crosses at different levels	Mixed crop-livestock farming, subsistence farming, intensive (zero-grazing) and pasture-based farming
KE	Holstein-Friesian, Ayrshire, Guernsey, Brown-Swiss, Boran and Sahiwal and their crosses	Mixed crop-livestock system, intensive farming, zero-grazing and pasture-based farming

ML	Holstein-Friesian, Jersey, Malawian Zebu; and their crosses	Mixed crop-livestock farming, subsistence and intensive (zero-grazing) farming
NG	Holstein-Friesian, Simmental, White Fulani (Bunaji), N'Dama, Sokoto Gudali (Bokologi), Muturu, and Red Bororo	Pastoral farming and mixed crop-livestock system
SE	Holstein-Friesian, Jersey, Normand, Brune de Alpes Montebeliarde, Zebu Gobra, N'Dama, Zebu Maure; and their crosses at different levels	Mixed crop-livestock farming, pastoral farming, subsistence farming, intensive (zero-grazing) farming, and pasture-based framing
SA	Holstein-Friesian, Jersey, Ayrshire, Guernsey, Dairy Swiss, Brown Swiss, Fleckvieh, FleckviehXHolstein-Friesian, FleckviehXJersey and Holstein-FriesianXJersey	Mixed crop-livestock farming, intensive (zero-grazing), and pasture-based farming
SU	Holstein-Friesian, Butana, Kennan, Arishy, White Nile; and their crosses at different levels	Intensive (zero-grazing) farming and pasture-based farming
TZ	Holstein-Friesian, Jersey, Ayrshire, Mpwapwa; and their crosses at different levels	Mixed crop-livestock farming, pastoral farming and intensive (zero-grazing) farming
UG	Holstein-Friesian, Jersey and Zebu	Mixed crop-livestock farming, intensive (zero-grazing) farming and pasture-based farming
ZW	Holstein-Friesian, Montebeliarde, Jersey,	Mixed crop-livestock farming and intensive (zero-grazing) farming

	Ayrshire, Sahiwal, Azawak, White Fulani, Tuli and Tarenatise	

n = 15 countries; Country Codes: BF (Burkina Faso), BR (Burundi); CA (Cameroon); ET (Ethiopia); GA (Gambia); IC (Ivory Coast); KE (Kenya); ML (Malawi); NG (Nigeria); SE (Senegal); SA (South Africa); SU (Sudan); TZ (Tanzania); UG (Uganda); ZW (Zimbabwe).

Either pure- or cross-breeding of exotic and indigenous dairy breeds were practiced at different levels in the various production systems. This helped to increase milk yield in cross-bred cattle and also optimise adaptability of the indigenous genotypes to the SSA environment.

Southern Africa used the most number of breeds for dairy production followed by Eastern and Western Africa. There were significant differences in the dairy breeds used for dairy production in the regions (P<0.01). Most exotic dairy breeds used for dairy production were found in the Southern (4.7 s.e = 0.5) compared to Eastern (3.2 s.e = 0.3) and Western (2.2 s.e = 0.3) regions in Africa. The most indigenous dairy breeds were in the Western (3.6 s.e = 0.3) followed by Southern (2.1 s.e = 0.4) and Eastern (2.1 s.e = 0.3) regions. In general, there were four main dairy production systems practiced in the three regions: mixed crop-livestock systems, intensive (zero-grazing) systems, subsistence farming systems, pastoral and pasture-based systems. There were no significant differences in the number of production systems used in practicing dairy production in the three regions. Predominant land tenure systems across the three regions included: communal, private and lease-hold. Number of such systems used was significantly different across regions. Table 3.5 summarises these results.

Table 3.5: Number of dairy breeds and dairy systems practiced in different regions of sub-Saharan Africa (marginal means from linear model).

	Dairy breeds				Dairy systems			
	Exotic		Indigenous		Production/ farming systems		Land tenure systems	
Regions	Frequency	s.e	Frequency	s.e	Frequency	s.e	Frequency	s.e
Eastern	3.2^{α}	0.3	2.1^{θ}	0.3	3.5^{θ}	0.2	2.0^{α}	0.13
Southern	4.7^{β}	0.5	2.1^{α}	0.4	3.7^{θ}	0.3	2.5^{β}	0.22

Western	2.2^{β}	0.3	3.6^{β}	0.3	4.0^{θ}	0.2	2.2^{β}	0.15

Footnotes: Different superscript in each trait denotes significant differences between regions (P<0.05). That is; **α** (significant); **β** (significant with other regions); **θ** (non significant).

3.3.1.3. Market organisation, proportion of milk consumed fresh and proportion of milk processed in sub-Saharan Africa

Table 3.6 shows a descriptive statistics of respondent views on the proportionate use of milk as consumed (fresh), milk processed into milk products and current marketing structure by respondent's country.

Table 3.6: Percentage of milk consumed as liquid (fresh) and processed milk in formal and informal markets in countries of SSA.

Country	Milk consumption as liquid (%)	Milk processed (%)	Milk sold in formal markets (%)	Milk sold in informal markets (%)
BF	40	Not stated	20	80
BR	100	0%	50 (40-60)	50 (40-60)
CA	100	0%	25 (20-30)	75 (50-100)
ET	85	15% processed into; butter, yogurts, among others	30 (20-40)	70 (40-100)
GA	Not stated	Not stated	30	70 (60-80)
IC	55	45%; gets wasted due to poor storage, or maybe processed	20 (0-20)	80 (80-100)
KE	89	11% is processed and sold to East African countries e.g. South Sudan, Rwanda	30	70
ML	65	35% processed and	40	60 (20-100)

		sold to countries like Zimbabwe		
NG	100	0%	20	80 (90-100)
SE	100	0%	30 (20-40)	70 (60-80)
SA	98	2%; sold to neighbouring countries for butter, cheese making	90 (80-100)	10
SU	20	80% is processed into dairy products	20	80
TZ	90	10% sold/exported for processing to dairy products	20	80 (90-100)
UG	100	0%	70 (60-80)	30(20-40)
ZW	65	35% sold/exported to milk processing industries	70 (60-80)	30 (20-40)

* Not stated; means respondents gave no answers and left space blank. Proportions are based on calculated averages of respondents by country. Country Codes: BF (Burkina Faso), BR (Burundi); CA (Cameroon); ET (Ethiopia); GA (Gambia); IC (Ivory Coast); KE (Kenya); ML (Malawi); NG (Nigeria); SE (Senegal); SA (South Africa); SU (Sudan); TZ (Tanzania); UG (Uganda); ZM (Zimbabwe).

The proportion of milk consumed as liquid was highest (100%) in BR, CA, NG, SE and UG. This implied that no milk was processed into dairy or dairy products in these countries. SU had the highest proportion of milk processed (80%) into dairy products. About 80% of milk produced within the SSA countries was consumed as liquid in the respective countries and very little was exported to industries mostly within Africa for processing into yogurts, cheese, ghee, butter and powdered milk products. In some cases, the small amount of milk produced was consumed by the small-holder farmers with very little milk sold to the market. In other instances, some of the milk got wasted (for instance in Ivory Coast) because of lack of either adequate storage or cooling facilities which also limited the amount of milk available to consumers. However, proportions of milk wastage could not be compared across all countries as such information was not available from the respondents. In TZ, GA and SU, dairy cows did not produce enough milk to meet the population's demands. Therefore, they had to source from other countries like SA and KE for fresh milk or rely on marketed powdered milk or milk substitutes. In general, proportions of milk sold in informal markets were higher (60%) than that sold in formal markets (40%) across respondent's countries. In most countries, majority of milk produced was sold in informal markets. Although, same proportions of milk (20%) were stated to be sold in both markets in SU.

The structure and organisation of the dairy market varied across the respondent's geographic regions. Proportions of milk sold in formal and informal markets were significantly different from zero across regions (P<0.01). Proportions of milk consumed as liquid (fresh milk) and milk processed did not differ significantly across regions. Table 3.7 summarises these results.

Table 3.7: Average proportion of milk consumed as liquid, milk processed and market structure in different regions in sub-Saharan Africa (marginal means from linear model analysis).

	Milk consumption and processing				Market structure			
	Milk liquid		Milk processed		Formal market		Informal market	
Regions	Mean (%)	s.e	Mean (%)	s.e	Mean (%)	s.e	Mean (%)	s.e
Eastern	85.2^{θ}	3.3	14.6^{θ}	3.0	33.0^{α}	2.2	63.4^{α}	2.6
Southern	81.2^{θ}	5.8	18.8^{θ}	5.2	65.9^{β}	4.1	34.1^{α}	4.6
Western	87.4^{θ}	3.8	7.8^{θ}	2.3	25.0^{β}	2.6	75.0^{α}	3.0

Footnotes: Different superscript in each trait denotes significant differences between regions (P< 0.05). That is; **α** (significant); **β** (significant with other regions); **θ** (non significant).

Compared to other regions, Southern Africa sold the most proportion of milk to formal markets while Western Africa sold the most proportion of milk to informal markets.

3.3.2. Differences between current status in dairy production between countries

Marginal means for existing dairy production status from the linear model for one country (Burkina Faso) were compared with the other 14 countries. Using Burkina Faso as a reference country, the current dairy situation and the significance in existing dairy production status varied a lot across the countries ($P<0.05$). However, production systems and land tenure systems in which dairy production was practiced tended to be similar and not significantly different within and between any two countries. Table 3.8 summarises differences between each one of the 15 countries against 14 countries with regards to current status of dairy production.

Table 3.8: Comparison among countries regarding current status of dairy production and marketing routes (Marginal means from linear model analyses).

Country	Milk Liquid (%)	s.e	Milk Processed (%)	s.e	Formal Market (%)	s.e	Informal Market (%)	s.e	No. of exotic breeds	s.e	No. of indigenous breeds	s.e	No of production systems	s.e	No. of land tenure systems	s.e
BF	40.0^{α}	5.0	$0.0^{\alpha,\beta}$	5.0	20.0^{α}	4.0	80.0^{α}	4.0	2.0^{α}	0.37	1.0^{β}	0.4	4.0^{θ}	0.5	1.0^{θ}	0.2
BR	95.0^{α}	5.0	2.5^{β}	5.0	47.5^{α}	4.0	52.5^{α}	4.0	1.0^{β}	0.37	1.0^{β}	0.4	4.0^{θ}	0.5	1.0^{θ}	0.2
CA	100.0^{α}	4.1	0.0^{β}	4.0	23.3^{β}	3.3	76.7^{β}	3.3	1.3^{β}	0.31	$2.7^{\beta,\theta}$	0.3	4.0^{θ}	0.4	2.0^{θ}	0.1
ET	$85.0^{\alpha,\beta}$	4.1	$15.0^{\beta,\theta}$	4.0	31.7^{β}	3.3	68.3^{β}	3.3	2.0^{β}	0.31	$1.0^{\beta,\theta}$	0.3	1.0^{θ}	0.4	2.0^{θ}	0.1
GA	100.0^{α}	5.0	0.0^{β}	5.0	30.0^{β}	4.0	70.0^{θ}	4.0	3.0^{β}	0.37	1.0^{α}	0.4	1.0^{θ}	0.5	1.0^{θ}	0.2
IC	58.3^{β}	4.1	41.7^{α}	4.0	23.3^{β}	3.3	76.7^{β}	3.3	$3.0^{\beta,\theta}$	0.31	3.0^{α}	0.3	5.0^{θ}	0.4	4.0^{θ}	0.1
KE	$88.6^{\alpha,\beta}$	1.6	11.4^{β}	1.6	32.5^{β}	1.3	$67.5^{\theta,\beta}$	1.3	$4.3^{\alpha,\beta}$	0.12	2.3^{α}	0.1	3.7^{θ}	0.2	2.0^{θ}	0.1
ML	58.3^{β}	4.1	$41.7^{\alpha,\theta}$	4.0	$30.0^{\beta,\theta}$	3.3	$70.0^{\beta\theta}$	3.3	1.0^{β}	0.31	2.0^{β}	0.3	4.0^{θ}	0.4	2.0^{θ}	0.1
NG	94.6^{α}	2.0	5.4^{β}	1.9	1.6^{β}	1.6	74.6^{β}	1.6	2.0^{β}	0.15	4.6^{α}	0.2	3.9^{θ}	0.2	2.0^{θ}	0.1
SE	100.0^{α}	5.0	0.0^{β}	5.0	27.5^{β}	4.0	$72.5^{\beta,\theta}$	4.0	2.5^{β}	0.37	5.0^{α}	0.4	5.5^{θ}	0.5	2.5^{θ}	0.2
SA	98.0^{α}	2.9	2.0^{β}	2.9	$82.5^{\alpha,\beta}$	2.3	$17.5^{\alpha,\beta}$	2.3	$6.8^{\alpha,\beta}$	0.22	1.2^{β}	0.2	3.8^{θ}	0.3	2.2^{θ}	0.1
SU	20.0^{α}	5.0	80.0^{β}	5.0	20.0^{β}	4.0	$20.0^{\alpha,\beta}$	4.0	1.0^{β}	0.37	5.0^{α}	0.4	3.0^{θ}	0.5	1.0^{θ}	0.2
TZ	88.3^{α}	2.9	11.7^{β}	2.9	22.5^{β}	2.3	2.3^{β}	33.3	2.3^{β}	0.22	1.5^{β}	0.2	4.0^{θ}	0.3	3.0^{θ}	0.1
UG	100.0^{α}	5.0	0.0^{β}	5.0	$70.0^{\alpha,\beta}$	4.0	$30.0^{\alpha,\beta}$	4.0	2.0^{β}	0.37	1.0^{β}	0.4	4.0^{θ}	0.5	1.0^{θ}	0.2
ZM	65.0^{β}	5.0	35.0^{θ}	5.0	70.0^{α}	4.0	30.0^{α}	4.0	$4.0^{\alpha,\beta}$	0.37	5.0^{α}	0.4	3.0^{θ}	0.5	4.0^{θ}	0.2

Footnotes: In reference to other countries; **α**: highly significant; **β**: significant with other countries; **θ**: not significantly different from other countries. Country Codes: BF (Burkina Faso), BR (Burundi); CA (Cameroon); ET (Ethiopia); GA (Gambia); IC (Ivory Coast); KE (Kenya); ML (Malawi); NG (Nigeria); SE (Senegal); SA (South Africa); SU (Sudan); TZ (Tanzania); UG (Uganda); ZW (Zimbabwe).

Eight countries (BR, CA, GA, NG, SE, SA, TZ, and UG) had significantly higher liquid milk consumption than average while countries (BF and SU) had significantly lower milk consumption ($P< 0.05$). This meant that higher proportions of milk are consumed as fresh or raw milk than being processed in each of these eight countries compared to the others. Also, two countries (BF and BR) had significantly lower than average proportion of milk sold in formal markets compared to a higher proportion in ZW ($P< 0.05$). No single country differed from the others with regards to number of land tenure systems and dairy production systems. While countries did not differ in number of land tenure systems used, there could be differences and variations in production systems used for practicing dairy production in the 15 countries in sub-Saharan Africa.

3.3.3. Strategic issues facing dairy production in respondent's countries in sub-Saharan Africa

Respondents identified the main factors and challenges affecting dairy performance recording and production systems in SSA. These included poor genetic assessment of imported exotic breeds and their crosses in Africa (62.32%), fluctuations in milk prices in both formal and informal markets (50.94%), inadequate genetic evaluations of individual animals and sires (39.62%), poor management systems in terms of herd health, feeding and housing (32.07%) and poor infrastructural facilities (30.30%), among others. Poor animal identification and recording, lack of systematic performance and pedigree recording were integrated into genetic evaluation factors since they constitute pre-requisites for national genetic evaluations. Inadequate market road network, poor storage, poor processing facilities, among others was incorporated into infrastructural facilities. It was identified that 65% of the milk produced is consumed within their countries while 27% identified challenges in milk processing. All these factors were significantly different from zero across the 15 countries ($P< 0.05$). Also, the key issues affecting dairy cattle recording and production systems differed significantly between countries than across the three regions (Eastern, Western and Southern Africa). However, across the regions, records on milk consumed, milk processed, production systems and land tenure systems were not significant. This may explain why almost 95% of respondents identified mixed crop-livestock systems in which dairying is practiced. This implies that the current dairy recording and dairy production systems varied significantly in countries in SSA.

3.4. DISCUSSION

The purpose of this study was to evaluate the current status of dairy data recording, dairy infrastructure, genetic improvement methods, existing human capacity and dairy production systems, and also to determine perceived solutions to strategic issues facing the dairy sector in the respondent's countries and geographic regions in sub-Saharan Africa. The survey served as the most convenient and relatively un-biased method of sourcing information from the respondent scientists working with small-holder or dairy farmers in the countries they are associated with in sub-Saharan Africa. The rather small number of respondents and lack of diversity in the profession of respondents is one of the limitations to our methodology/approach. Despite the fact that 14% responses from the survey are considered an appropriate sample size, this may be small in reflecting the overall current human capacity in the 15 countries and regions. While dairy infrastructure, capacity, dairy production systems and challenges of dairy production could vary across the countries and regions; the survey reflected a synopsis of the current situation facing the dairy industry in Africa as a whole.

Variations in milk usage across country and region have been affected by socio-economic factors such as milk cost, poor storage facilities, milk availability and farmer's preference. For instance in Kenya, consumption of raw milk is common accounting for 85% of all cow milk produced and has been found to be 20 to 50% cheaper than processed milk (Muriuki, 2011). This may be the reason why raw milk consumption was higher than milk processed in Kenya as compared to other countries in Eastern Africa in our present study. Nicholson *et al.* (2003) highlighted that fresh ("raw") milk was generally preferred to the ultra heat treated (UHT) and pasteurised milk in some parts of East and West Africa. Most developing countries in SSA are net importers of dairy products from developed countries (Skoet and Gerosa, 2012). African dairy product market is speculated to have an increased number of organised players in the future which could lead to an intensive and competitive market for various dairy products (Ken Research, 2016). This competition will aid in the decrease of dairy product prices and hence enhance the availability of processed milk to these countries for the future. The preference for raw milk (Kembe *et al.,* 2008) is generally more marked in the rural areas (Smallholder Dairy Project, 2004). This might be the reason for high milk consumption as liquid especially in rural Western Africa. The region of Southern Africa has the most stable dairy production strategy (Department of Agriculture, Forestry and Fisheries, 2012) in Africa and milk processed there was higher (~19%) than other regions with South Africa taking the lead. Studies have showed that milk produced and processed from South Africa are exported to other neighbouring countries and regions with low production (Muriuki and Thorpe, 2006; Ndambi *et al.,* 2007).

In sub-Saharan Africa, the milk market is bi-sectorial comprising, formal and informal ("traditional") markets. Informal dairy market dominates Kenya, Uganda, and Sudan (Silali and Shimba, 2017).The current marketing routes for milk and milk products in respondent's countries was 60% higher in informal markets with less variation as compared to formal markets (40%). Milk prices in formal markets are usually low, licensed and controlled compared to informal markets (Brokken and Seyoum, 1990) hence, the fluctuation in prices in the latter in our present study. In sub-Saharan Africa, the informal sector accounts for 60% of the economy (Willemse, 2011) which was the same in the present study. This is because the sector is able to accommodate a wide range of individuals including the young, old and uneducated. Across the regions, informal markets dominate Western Africa and Eastern Africa. The estimates for the proportion of total marketed milk sold formally in our study were relatively low but slightly higher than those reported in literature. For instance, the proportion of total marketed milk sold formally is very small; < 5% in Ethiopia (Tsehay, 2002), 15% in Kenya (Omore *et al.,* 1999), 5% in Tanzania (Omiti and Staal, 1996) and 5% in Uganda (Kurwijila, 2002). According to the International Livestock Research Institute, the informal dairy industry in the East and Central Africa region plays an important role in milk marketing and handles over 85% of all milk sold (ILRI, 2011). The informal sector also provides small-holder families with a nutritious, affordable product and generates income and employment to thousands of dairy marketers and service providers (Becker, 2004; Omore *et al*., 2004).

In informal markets, milk is sold in varying prices compared to more uniform prices in formal markets. In addition, the formal markets require certain criteria or standards in terms of milk quality and milk hygiene which some of the farmers are not likely to achieve. At times, some formal markets may not be accessible to some small-holder farmers possibly due to poor road networks, poor storage facilities, and very high requirements of dairy processing companies regarding milk properties including quality, quantity and hygiene. Despite the fact that the informal sector serves as major source of provision of goods and services for poor households, there are still limitations (Skinner, 2008). The prices of goods and services are not stream-lined (Willemse, 2011). Another theory in milk price fluctuation is due to unorganised, small-scale farm businesses in informal markets or milk consumed directly at home (Staal, 2006). Milk sold in formal markets must meet the requirement of dairy processors who are keen on milk quality, milk components and public health concerns. The milk which does not make it to the formal market frequently, does not meet these criteria and is therefore sold in informal market at very low prices, thereby incurring financial losses to the farmers. Most times, informal markets could pose a health risk of zoonotic diseases. Therefore the need for education of boiling such milk before consumption is essential. In some countries, milk prices tend to be higher in both markets as growing demand for milk does not meet supply. Also, some farmers who sell milk in the formal markets also sell part of the milk informally to gain more profits on milk sales to cover cost of inputs in their dairy farms. These farmers do this because of either lack or no incentives from the dairy sector or government to boost the requirements of their dairy herds. More support in terms of subsidies and incentives to small-scale farmers, would aid in optimising milk prices across both markets. Also, many governments of SSA have to address how best to ensure fair competition and uniformity between the formal and informal markets (Staal, 2006). This is to the benefit of producers and consumers, most of who are in low-income households (Muriuki, 2003).

Current status of animal recording, dairy improvement infrastructure, capacity and policies

In most African countries, there is a lack of systematic pedigree and performance recording as well as proper animal identification. Few countries in East Africa have developed appropriate policies and implemented centralised systems of animal monitoring, selection and crossbreeding for dairy sheep and goat improvement with varying degrees of success (Salami *et al.,* 2010; Duguma *et al.,* 2011). For instance, in Kenya, the Dairy Development Policy of July 1993, National Livestock Policy and the Dairy Master Plan (Dairy Act 366) were drawn for genetic improvement with target on dairy production. The policies are aimed at improving milk yield potential via crossbreeding with exotic breeds; promote productivity among small-holder farmers, and also to support the farmers to acquire good breeding stock. The Kenyan dairy sector is thriving in this respect and governments of some countries in Eastern and Southern Africa have taken up the initiative to promote dairy industry in their countries. This was evident in the response rate, human capacity, dairy market routes, dairy breeds and production systems practiced in respondent's countries of the Eastern and Southern regions.

In Nigeria, the Agricultural Transformation Agenda Support Programme (ATASP), sponsored by the African Development Bank Group, was established in 2013 by the Nigerian federal government to assist small-scale farmers and rural entrepreneurs (AFDB, 2013). The primary aim was to improve the income of small-holder farmers and rural entrepreneurs that are engaged in the production, processing, storage and marketing of selected commodity value chains. The Nigerian government through ATASP has mandated the commercial milk and milk products producing companies to start collecting milk from dairy farmers so as to enhance availability to consumers. ATASP also regulates improved breeding through artificial insemination (AI), milk hygiene, and milk marketing through organised cooperatives. From the current study, the proportion of milk consumed as fresh milk and milk in informal markets was greater compared to processed milk and milk sold in formal markets. The ability to meet small-scale farmer, rural entrepreneur and consumer demands prompted the development of ATASP in Nigeria. In Ivory Coast, there are emerging projects like; the joint venture of a Danish dairy company; Arla®, Mata Holdings® and the local government with the aim of processing, packaging and distribution of milk produced in Ivory Coast into milk products (Dairy Reporter, 2013). The joint partnership with Mata Holdings® ensures the packaging and distribution of single-portions of the Danish-Ivory Coast milk powder into 25 grams milk sachets. This is to meet the increased demand and supply for milk to Ivorian consumers and neighbouring countries like Ghana, Namibia and Rwanda.

The influence of small-holder dairy production on rural economies has resulted in substantial development support for the farmers from both national and international agencies (Chagunda *et al.*, 2015), including non-governmental organisations: the Bill and Melinda Gates foundation (BMGF), Clinton Foundation and Heifer International (HI). Other dairy improvement initiatives that have been developed by governmental organisations include; the United States Agency for International Development (USAID), African Dairy Genetic Gain (ADGG), the International Fund for Agricultural Development (IFAD), Stichting Nederlandse Vrijwilligers Netherlands (SNV), the Natural Resources Institute Finland (Luke), Food and Agricultural Organisation (FAO) and dairy co-operatives; Land O' Lakes Company (Tolessa, 2010). This has led to the "springing up" of various technologies to boost milk production and to empower poor families and small-holders farmers to improve their standard of living, income source and also increase the number of milking animals in their herds. Furthermore, the government in some SSA countries have provided subsidies and supports in terms of veterinary drugs and services, and provision of young heifers to small-holder farmers so as to improve their herds (Gitahi, 2003; ILRI, 2003; Ezeanya, 2014).

A few countries like; Tanzania, South Africa, Kenya, Burundi and Ethiopia have tried to make accessibility to markets easier for the farmers through provision of good road networks (Nahdy, 2002; Tsehay, 2002; Kuma *et al.,* 2013). Certain countries also built infrastructure and service provision to facilitate and support the dairy sector. For instance, in Kenya, there are government-owned research institutes that perform data recording and genetic evaluations (Muriuki *et al.,* 2003; Muia *et al.,* 2011) such as the Kenya Livestock Breeders Organisation (KLBO), International Livestock Research Institute (ILRI), Livestock Recording Centre (LRC) and Kenya Genetic Resources (KGR). In South Africa, data recording and within breed genetic assessments (Mostert *et al.,* 2006; Banga *et al.,* 2014) are being carried out by the Agricultural Research Council (ARC) and some university research institutes such as the Stellenbosch University. In Malawi, data recording (Galal, 1998; Chagunda *et al.,* 2006) is performed by research institutes like the Lilongwe University of Agriculture and Natural Resources. Also, data recording in Malawi has been made easier for dairy farmers by providing mobile technologies via the use of cell phones so as to supply milk quantities to milk collection centres for recording. In Nigeria, milk recording is predominantly done by National Animal Production Research Institute (NAPRI). Subsidies are provided to small-holder farmers in form of breeding stocks, access to veterinary services, and ambulatory services to dairy farms outside the main road networks. However, all these need to be further improved in order to enhance milk yield to the level that it meets the rising demand in sub-Saharan Africa.

The majority of data collected in sub-Saharan Africa is on milk yield. Other types of data collected include pedigree, reproduction, herd health, economic records, milk quality, breed type, farm herd ownership and location. In most cases, there are no adequate schemes for systematic and regular recording in place. Some small-holder farmers do not have access to the existing recording system at all. For instance, pastoralist and dairy nomads are mobile and travel from one place to another in search for green pastures and water for their animals. Therefore, it is very difficult to keep track of their cows, herds and milk records. South Africa and Kenya have a good and official recording system for milk yield, reproduction, pedigree and herd health on local, exotic and crosses, although there are low levels of participation of farmers. Records taken in South Africa are basically on milk, fat, protein yields, reproduction and herd health data of exotic, local and their crosses from farmers involved in dairy production. These records are taken following the International Committee for Animal Recording (ICAR) guidelines (Jorjani *et al.,* 2001) as South Africa (SA) has since been a member in 1999. In South Africa, two dairy sectors; SA Stud Book and the SA Agricultural Research Council have also received ICAR's Certificate of Quality. This is a recognition that ICAR members adhere to the relevant guidelines and standards in its activities, and that the work it does is professional and internationally recognised. Other African members of ICAR are Egypt, Tunisia and Morocco but have not attained the ICAR's Certificate of Quality.

Malawi, Senegal, Nigeria and Ethiopia have rudimentary milk recording systems which are gradually growing but no substantial record processing including genetic evaluation of the animals is being performed yet. However, some university-owned or research farms do some forms of genetic evaluation and data recording on a limited scale. In Ethiopia, a national artificial insemination centre was recently developed in Addis Ababa. Higher education research centres like Lilongwe University of Agriculture and Natural Resources take performance records in Malawi and some forms of within breed genetic evaluation have started to occur. Gambia, Cameroon and Sudan do not have any form of population-wide recording system in place. Although, the Atbara Livestock Research station in Sudan conducts a limited regional scale recording in Sudan. Farmers who participate and benefit from the recording systems include those involved with large estates, mixed crop-livestock farming, zero-farming and intensive farming. Other participants in milk recording include; breeding farms as well as, research institute and university dairy farms. Farmers involved in back-yard farming, nomadic farming, subsistence farming and pasture-based farming may or may not participate and in addition, benefit to a lower extent from recording systems. Therefore, a model that incorporates more farmers by including pastoralists and cows along cattle routes into an adequate recording system is needed so as to track their dairy population, production, reproductive performance and health of their herds.

Almost all countries, with the exception of South Africa, are lacking proper genetic evaluation systems to produce systematic sire ranking for selection purposes. Attempts were made in the past in some countries but failed due to lack of continuous government support, inadequate financial resources, inappropriate breeding plans, lack of scientific expertise and also lack of participation by dairy farmers. In some cases, past attempts to genetic improvement included upgrading local genetics with imported high yielding milk breeds (e.g. Holstein-Friesians). However, initial breeding between the Holstein-Friesians and indigenous breeds was by visual selection (Njarui *et al.,* 2012) and not dictated by genetic information. These were “short-cuts” that also totally ignored the issue of environmental adaptability and availability of appropriate feed and feed resources. There was an attempt to establish a studbook in the previous East Africa Community (EAC) in the early 1990s but after the EAC collapsed in 1977, only Kenya continued the programme (FAO, 2007). The problem probably was due to change of government and national priorities in the different countries (FAO, 2011). This effort coincided with the colonial era in some countries and got abandoned when the British and French colonials left Africa and nobody else would take the interest to continue. Also, some farmers saw it as a form of “competition” among herds or farms rather than working towards a common goal.

On average, women account for 40 percent of the agricultural labour force in developing countries and ranging from 20 percent in Latin America to 50 percent or more in most parts of Africa and Asia (FAO, 2018). In sub-Saharan Africa, it is known that women are mainly involved in the welfare and milking of dairy cows in small-holder farms than their male counterparts (IFAD, 2006; 2010). There has been a general lack or poor involvement of women in education. This has been due to the fact that women are seen to be those who “stay at home” to cater for the family while the men are given opportunities for higher education. However, it has been shown that these women apply their mothering ability to their animals as they pay more adequate attention than men. Although, a low response rate (10%) was observed in females represented as animal experts, a survey that captures more women represented in agriculture will be beneficial in identifying educational gaps that require improvement for the future. Kinambuga (2010) highlighted the need for human capacity and infrastructure for decision-support systems. Therefore, the training should focus on improved husbandry practices for the local women who currently look after the animals. Also, it is necessary to enlighten and empower the African men and women to get them involved in education and train them into scientists. Also, capacity building could be enhanced through the provision of funds, scholarships and incentives to both young boys and girls to attend higher education so as to enhance gender equality and diversity particularly, in the field of science, animal husbandry, breeding and genetics.

Strategic issues facing dairy production in respondent's countries and regions

Dairy production serves several purposes for the livelihood of small-scale farmers in sub-Saharan Africa. For instance, dairy cattle are used for traction purposes ("beast of burden") to decrease cost of human labour (Kamuanga *et al.,* 2001), and improve total farm output and incomes through increased milk production (Starkey and Kaumbutho, 1999). Manure obtained from the cattle is used to fertilise the crops. Despite, the advantages, there are still numerous challenges facing the African dairy production sector which need to be addressed so as to meet the target for demand and supply of milk by 2025 (Delgado, 2005) and 2050 (Alexandratus and Bruinsma, 2012). Some targets have been met by some forms of national evaluations of various exotic and cross breeds in African countries such as Ethiopia, South Africa, Kenya, Zimbabwe, Tanzania, Nigeria, Ghana, Sudan and among others (Ramatsoma *et al*., 2014; Alphonsus *et al*., 2015).

Key issues facing African dairy production as highlighted by the survey in the present study have been reported in the literature also (Bebe *et al.,* 2003; Delgado, 2005; Steinfield *et al*., 2006). Therefore, the need was emphasised for across-country collaborations and genetic assessment of exotic, indigenous breeds and their crosses in SSA as a means to enhance dairy production and future genetic gains (VanRaden and Sullivan, 2010; vanMarle-Köster and Webb, 2014). There is a lack of adequate accessibility to the milk markets by dairy farmers. This is mainly due to bad road networks and poor transport facilities. Therefore, farmers have to walk long distances to market sites, milk collection points and milk banks to meet prospective buyers. In most cases, the prospective buyers do not meet the farmers at their farms to purchase milk. This leads to some of the milk being spoilt or wasted as these rural farmers do not have adequate and appropriate storage facilities. Milk wastage and spoilage may also be due to interruption of milk supply chain by numerous marketing agents before reaching the consumer (Staal *et al.,* 1997; Staal, 2006).

There are poor animal performance recording systems (Ehui *et al.,* 2009) while some countries still do not have the appropriate technologies for collating data (Staal, 1996; Muia *et al.,* 2011). There are inadequate comprehensive sire genetic evaluation systems (Banga *et al.,* 2008), poor marketing routes for dairy products and poor infrastructural facilities (Delgado *et al*., 1999). Dairy farmers lack adequate government support which may be due to political instability and lack of interest by government officials in dairy farming. In addition, there is inadequate uptake of genetic technologies, poor genetic assessment of imported and foreign (exotic) breeds and crosses in Africa (Duguma *et al.,* 2011; Nielsen *et al.,* 2013). Most dairy cows in small-scale farms are exposed to poor feeding (Martin-Collado *et al*., 2015) housing and health management regimen which adversely affects milk yield (Delgado, 2005). There is a huge demand to improve dairy production and performance in the foreign (exotic), local and their cross breeds used in sub-Saharan Africa.

Perceived solutions to strategic issues facing dairy improvement infrastructure in sub-Saharan Africa

Mitigating and alleviating the above-mentioned issues in dairy breeds will help to increase milk yield and its sustainability in Africa. For instance, de-Ridder *et al.* (2015) emphasised that the adequate availability of feed supplements during the dry season for indigenous breeds such as the West African Mére breed could help to improve milk production among small-holder farmers in Southern Mali. This is because the breed is known for its adaptation to mixed crop-livestock system and for high milk and beef yield (Kamuanga *et al.,* 2001). A similar study by Lalba and Dickey (1996) in Burkina Faso showed that with improved feeding and good grazing management practices, milk production and calf growth could be increased. The survey respondents in the present study highlighted the impact of advanced reproductive technologies such as the use of artificial insemination and importation of young exotic bulls and heifers to boost the current indigenous breeds in Africa. A tremendous increase in quantity of milk yield, disease resistance and adaptability to the African environment of the F_1 generation of exotic and indigenous type over the indigenous breeds has been observed (Philipsson, 2000; Alphonsus *et al.,* 2015). In addition, the assessment of breeding values of foreign (exotic) bulls and sires currently in SSA environment could inform future genetic improvement strategies (Ojango *et al.,* 2005).

There has been a rising demand for milk and milk production in SSA (Nkwasibe *et al.,* 2015). This is due to increased human population and socio-economic status with a corresponding decrease in milk output from dairy cattle. Therefore, the number and productivity of milk and meat animals will have to increase in order to meet the rising demand (Steinfield *et al*., 2006) without diminishing Africa's national resource base (Rege *et al.,* 2011). Studies by Delgado (1999) and Holloway *et al.* (2000) have shown that the demand for milk and milk products is expected to increase by only 4% over the next decade unless adequate measures are put in place to further improve milk productivity. A major increase in the production levels to meet this demand is very important (Scholtz and Theunissen, 2010; Scholtz *et al*., 2011). The type of breeding and production system to be implemented will depend primarily on improving the management system and environmental conditions of both indigenous and exotic breeds. This will involve the genetic selection of breeds that are able to thrive well in the African condition and step up level of production. As part of improving milk production performance, effective and efficient policies and programmes are required for the genetic improvement of livestock. The importance of these policies is to regulate milk production, availability and marketing. Respondents identified the limited supply of milk and the fluctuations in milk prices between the formal and informal markets in SSA. Generally, it has been shown that informal markets tend to thrive better than formal markets because the former provides critical economic opportunities for the poor rural farmers (Nkwasibwe *et al.,* 2015). Respondents highlighted on the need to improve and enhance dairy improvement, infrastructure and human capacity. Therefore, in order to achieve this; the following crucial or perceived solutions pointed out by respondents can be considered;

Firstly, the improvement in the availability of feed and feed resources for dairy cows is the main issue that needs to be tackled in order to improve and enhance optimum milk yield. A constant supply of feed is necessary in terms of quality and quantity, forage and pasture availability. This will help to harness the genetic potential of breeds which have the ability to produce more milk than others. Developments of small-scale silage technologies to store forage and pasture so as to prevent scarcity and to meet an all-year round demand of dairy cows is warranted. Feed formulation and conservation will be essential in periods of drought where there is either shortage or poor supply. There should be improvement in feeding to match improved and current genotypes in African environment.

Secondly, there is need to ensure the presence of an ever improving and efficient centralised animal performance recording system by enacting relevant dairy policies, training personnel, capacity building and ensuring financial viability. Currently, 95% of countries in SSA do not have an efficient animal identification and recording system in place. Farmer participation is probably the most crucial component for the success of such initiative. There should be incentives for dairy farmers to participate in dairy performance recording. These include: sustainable access to feed and feed resources (e.g. hay, silage, fodder, cut grass etc.) all year round, dairy storage facilities, adequate veterinary services and rural infrastructure. Also, the establishment of a dairy incentive pay programme that ensures that dairy farmers are rewarded directly and effectively for milk performance, quality and milk components (in terms of protein, fat, and somatic cell count), herd health and hygiene, improved heifer pregnancy and calving rates should be considered in dairying in Africa.

Thirdly, a unified dairy national policy guiding dairy development and improvement in each African country is necessary so as to ensure fair and reasonable milk prices in both formal and informal markets, and better organisation of farmers into breeding or milk bulking groups. Also, an adequate structural and organised breeding policy that can be adhered to is essential. Such policies will improve accuracy of selection in terms of accessing the appropriate exotic and indigenous breeds and their crosses by developing breeding specifications and plans.

Fourthly, dairy farmers should have access to genetically improved breeds and superior animals selected on the basis of formal genetic evaluations. Farmers would also need advice and support as to which sires to select for breeding in their farms. There should be adequate supply and multiplication of genetically superior dairy heifers, while enhancing the performance of indigenous breeds through availability of proven technologies and the characterisation of appropriate breeding stock. Also, a system for determining the breeding values of foreign sires used in Africa should be established and used for genetic selection rather than using breeding values of their countries of origin (Bebe *et al.,* 2000). In addition, there should be extensive artificial insemination services in the traditional herd especially among small-holder dairy farmers who have become the primary source of milk production to the populace in recent years. Survey respondents expressed the need for national and international genetic evaluations of the current foreign (exotic) dairy breeds currently used in Africa so as to optimise genetic gains and dairy improvement strategies.

Fifthly, there is need for improved infrastructure in terms of good road networks for accessibility to milk markets, bulking centres, milk collection centres and access to milk storage facilities (Muriuki, 2003; Alemu, 2016) to avoid wastage and spoilage of milk before it gets to consumers or processing facilities. In addition, there should be an improvement in farm management practices in terms of disease control and prevention through accessibility of veterinary services. For instance, by providing drugs, vaccinations against endemic diseases in Africa and other veterinary/ health services at subsidised rates to dairy farmers. There should be formation of strong dairy farmer organisations in these regards e.g. associations and cooperatives where these do not exist.

Sixthly, government support and involvement in the dairy sector is needed via partnership with dairy farmers and stakeholders to ensure funds are targeted towards improving dairy production. This will empower the small-holder farmers through providing incentives and subsidies in terms of reduction in cost of feed, breeding stocks, accessibility to veterinary services and land availability for dairy farming. Furthermore, Kurwijila (2002) stated that improvement in the dairy sector should require regulations by the stakeholders themselves rather than governmental controls. This implies that the dairy industry will have to organise itself to face challenges of today and the future. Government of some countries have endeavoured in introducing the “one cow per family” policy to support dairy farmers who keep predominantly indigenous breeds in the herds so as to step up milk yield (Ergano and Nurfeta, 2006; Odero-Waitituh, 2017)

Seventhly, there is the need for capacity building in sub-Saharan Africa. Response rate to the survey was lower in females as compared to males. In general, a sizeable gender gap exists between women's and men's participation in the information and knowledge society where men are giving more privileges and job opportunities than women (Mósesdóttir, 2010). While evidence suggests, that globalisation has given some employment opportunities to skilled and educated women in developed countries, its impact on the gender division of labour in developing countries has not yet materialised (Khalafzai and Nirupama, 2011). Therefore, there is a need to bridge this gap in Africa by empowering women or individuals with educational incentives. Public enlightenment could encourage them on the need to pursue an academic career in either science or other subjects relating to animal breeding, husbandry and genetics, so as to secure livestock production for the future. Also, more capacity can be built via ensuring training of personnel especially women in the animal breeding and husbandry work force through providing job opportunities, to ensure gender equality in Africa. This will in turn empower women and the coming generation of young-girl empowerment and involvement of women in science as done in the developed world.

Efficient genetic improvement within and across countries and regions in sub-Saharan Africa would help optimise dairy production. The decrease in the use of genetic tools and breeding tools among livestock farmers is one of the setbacks that inhibit the optimisation of genetic gains in breeding programs (Martin-Collado *et al*., 2015). It is therefore, necessary to take into consideration what farmer's preference are; in terms of dairy breed improvement and milk optimisation. Selection for replacement animals from exotic and indigenous dairy breeds with outstanding genetic merits would aid in increased genetic response for milk performance trait and other desirable traits under selection. Therefore, it is becoming more important to note that matching exotic and indigenous genotypes born in SSA to its environment will ensure sustainability in milk production by defining breeding goals and objectives. Also, developing adequate selection criteria for breeding will aim at sustainable production even in a changing tropical environment.

Most countries in Africa import genetic material such as embryo or semen for embryo transfer and artificial insemination from the United States of America, Canada, New Zealand, United Kingdom and other parts of Europe (Bebe *et al.,* 2003; Ndambi *et al.,* 2007). However, the genetic components and their genetic capacity within the sub-Saharan African terrain require adequate investigation so as to maximise their genetic potential. In general, the need of having a strong national animal identification, performance recording, livestock breeding and evaluation system within each country will form an important basis for embarking on a successful, sustainable and effective joint across-country genetic evaluation for dairy improvement and milk productivity in sub-Saharan Africa. Therefore, the need for across country evaluation (ACE) programs as highlighted by the countries will be essential and have a tremendous benefit in improving milk yield in Africa. This will help to determine breeding values of sires whose daughters born in Africa occur in various herds and farming systems that are currently practiced in sub-Saharan Africa. Also, researchers and animal experts need to engage in dialogue intensively with farmers and stakeholders so as to address some of the key problems and needs affecting small-holder dairy production for sustainable future breeding strategies and optimised genetic gains.

The survey helped in considering the need for within and across-country collaborations through genetic evaluations of foreign and indigenous dairy breeds currently in SSA. The survey served as an efficient route for sourcing views and information from these respondents who are either animal experts or scientists working with African dairy production systems as currently practiced. This serves as a better initiative as opposed to FAO statistics in sourcing the appropriate views and suggestions of the respondents working with these systems and how they could be improved.

Lastly, public enlightenment of individuals and prospective farmers in Africa to engage in livestock or dairy production should be considered. The Establishment of learning hubs and training centres in Africa should be developed and considered as a means to train individuals and farmers involved in dairy production. Dairy production in sub-Saharan Africa promises a huge potential to improve the farmers' income and contribute to the overall rural development and prosperity if there is an adequate dairy infrastructure in place.

3.5. CONCLUSION

This chapter has highlighted the current status and some of the strategic issues limiting dairy productivity in SSA. These included issues of animal recording, poor infrastructure and limited human capacity. The Chapter also outlined some solutions on how these strategic issues can be tackled for optimisation of dairying in SSA. The current situation of dairy production though similar for the different countries, differed in order of emphasis and magnitude across the countries and regions in sub-Saharan Africa. However, the perceived solutions were the same across the countries and regions in SSA. Respondents emphasised the need for adequate data recording and animal identification systems, updated breeding policies, sire ranking systems, adequate farm management systems, capacity building (farm advisory, trained breeders and others), joint genetic assessments of dairy breeds and across-country collaborations. This should be exemplified by common breeding schemes that could be implemented to revolutionise dairy production and enhance joint genetic evaluations in SSA. The need for joint genetic evaluations was emphasised so as to underpin across-country breeding programmes aiming to maximise animal productivity in SSA. Joint genetic evaluations including data from different sub-Saharan African countries are addressed in the following Chapters.

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CHAPTER 4

4.0. Within and across-country genetic evaluations for Holstein-Friesian and Jersey dairy cattle performing in Kenya, South Africa and Zimbabwe

4.1. INTRODUCTION

Milk yield in dairy cattle depends on both the genetic background of the animals and management systems in which the cows perform. The interaction between genotype and the environment (GxE) could also play a vital role in how animals of different genetic merit realise their genetic potential (Hurtado-Lugo *et al*., 2011; Wakchaure *et al.,* 2016). Cow milk is one of the most significant agricultural commodities contributing on average about 32% to the gross domestic product (GDP) in sub-Saharan Africa (FAOSTAT, 2006). In Kenya, dairy production accounts for 43% of agricultural GDP (Staal *et al.,* 2003; FAOSTAT, 2016), in South Africa 34% and in Zimbabwe 26% (FAOSTAT, 2015). In most countries in Africa, the genetic potential of dairy cattle has not been fully expressed due to either absence of or inadequate genetic improvement strategies. This has been demonstrated in several studies where phenotypic yields have been low and genetic progress over the years has been close to zero (Ilatsia *et al.,* 2007; Makgahlela *et al.,* 2007; Scholtz *et al.,* 2013). Apart from poor management systems and practices, genetic improvement has not been carried out systematically in most sub-Saharan Africa countries (Banga, 2009; VanRaden and Sullivan, 2010; Van Marle-Köster and Webb, 2014). In addition, there has been lack of performance and pedigree information recording in most African countries (Bebe *et al*., 2003; Kosgey *et al.,* 2006; Rege *et al.,* 2011).

Genetic improvement of farmed livestock may have a major impact on productivity. The process is usually highly cost-effective and its effects are permanent and cumulative (Hill, 2016). The main objective of an animal improvement programme is to improve the genetic merit in animals for efficient and sustainable productivity across generations (Snijders *et al*., 2001; VanRaden and Sanders, 2003). Achieving this goal involves the identification of those animals with the best breeding values and then ensuring that the selected individuals become parents of the next generation. Genetic improvement in dairy cattle in Africa has included the importation of Holstein-Friesians for pure- and cross-breeding with indigenous breeds (Chagunda *et al.,* 2015). Currently, most of the exotic breeds used for dairy production in Africa are sourced either as live animals or as semen from the United States of America, Canada, Europe, Australia and New Zealand (Maiwashe *et al.*, 2006). Holstein-Friesian is the most common exotic breed used for milk production in sub-Saharan Africa (Banga, 2009). Jersey is the second most common exotic breed followed by Ayrshire and Guernsey (Maiwashe *et al*., 2006). Jerseys are popular for high butterfat content of their milk and have lower maintenance costs due to their lower bodyweight. However, there is paucity of information on economically important traits and genetic evaluations of this breed in Africa. Most studies have mainly focused on production traits (Missanjo, 2010; Missanjo *et al.,* 2013).

International or across-country genetic evaluations of dairy cattle reared in different countries may provide the tools for more effective management of the breeding programmes including international comparison and trade of genetic material. The potential utility of these tools has been previously demonstrated (Banos and Smith, 1991). Across-country genetic evaluations are currently available through the International Bull Genetic Evaluation Service (InterBull; www.interbull.org) to the major dairy producing countries of the western world. These evaluations require the presence of systematic genetic improvement programmes within country and collaboration between countries. In most African countries where dairy cow populations are rather small, the need for a joint or across-country genetic evaluation for major animal traits becomes even more important. However, joint genetic evaluations of major dairy breeds such as Holstein-Friesian and Jersey performing within SSA have not been carried out, yet. The hypothesis is that joint genetic evaluations would generate more accurate genetic parameters of traits and estimated breeding values of individual animals. The objectives of the present study were to (i) calculate and compare within- and across-country genetic parameters for production and reproduction traits using data from three sub-Saharan countries and (ii) compare breeding values of individual animals estimated through within- and across-country genetic evaluations.

4.2. Data

4.2.1. Data origin

Performance data of Holstein-Friesian cows were obtained from Kenya, South Africa and Zimbabwe. Animal records from the Kenyan Livestock Breeders Organisation (KLBO), Kenya Agricultural and Livestock Research Organisation (KALRO) and Kenya Stud Book (KSB) were made available through the International Livestock Research Institute; data from Zimbabwe were provided via National Animal Recording and from South Africa via the Agricultural Research Council. Data pertained to milk, butterfat and protein yields. Test-day milk yield records were provided for Kenya and Zimbabwe while lactation yield records were provided for South Africa. Herd address information was not provided in the South Africa data but for Kenya and Zimbabwe data. Data also included reproductive events from which age at first calving and calving interval were calculated for each cow. Holstein-Friesian data from Kenya were for cows performing between 1979 and 2014 while for South Africa and Zimbabwe data were from 1997 to 2014 and 1998 to 2012, respectively. Information on lactation number in Zimbabwe was not available. Therefore, age at calving was used to infer lactation number based on animal age per lactation in the data from South Africa and Kenya. This process was informed by first using a small training dataset from South Africa and Kenya before applying the rule to the dataset of study. Similar data were available for the Jersey breed from Kenya and South Africa. South African data were for the period between 1999 and 2013 and Kenyan, between 1989 and 2010. For both breeds and countries data, only sires born between 1985 and 2000 were included in the joint genetic analyses. Table 4.1 shows structure of unedited data provided by the three countries for the two breeds.

Table 4.1: Original unedited data structure provided from Kenya, South Africa and Zimbabwe.

	Kenya		South Africa		Zimbabwe
	Holstein-Friesian	Jersey	Holstein-Friesian	Jersey	Holstein-Friesian
Number of test-day records	358,327	46,242	-	-	260,747
Number of 305-day milk yield records	-	-	10,767,516	1,858,021	-
Number of cows	18,868	1,965	377,921	118,255	7,742
Number of herds	384	113	1,056	1,150	297
Number of sires	2,617	233	7,397	5,722	285
Number of dams	7,849	1,177	135,703	138,890	3,287
Average test-day yield (Litres)	13.04±6.71	12.10±5.32	-	-	8.62±3.61
Average 305-day milk yield (Litres)	-	-	8,237.82±2,560.10	5,464.14±1,389.73	-

Performance records provided were from small, medium and large-scale dairy farming systems. Test-day yield and 305-day milk yield were derived as means and standard deviation for each of the countries. Although all datasets had the herd identification, information on the herd location was only provided for Kenya and Zimbabwe but not for South Africa.

4.2.2. Data edits

Appendix 4 shows details of edits applied to the unedited data in Table 4.1. The following criteria were used to perform edits using the R package (R Core Team, 2013): cows without a first lactation, cows with missing records, and records missing date of birth, test-day date, date of calving and herd address were excluded from the analysis. Editing also applied age restrictions within parities to ensure reasonable ages at calving per parity. This was set according to restrictions used in the South African National Dairy Genetic Evaluations (Mostert *et al.,* 2006). Lactation milk yield less than 305 litres and calving intervals shorter than 300 days were not included in the analysis (Makaglela *et al.,* 2007; Banga, 2009). A maximum of 48 months was applied for age at first calving.

In South Africa, two calendar seasons of calving were defined according to Mostert *et al.* (2006): a wet season from April to September and a dry season from October to March. In Kenya, the dry season was from December to March and also from July to October while the wet season included April to June and also November (Stotz, 1993; Ojango and Pollott, 2002). In Zimbabwe, the wet season was from September to April while the dry season was from May to October (Gusha *et al.,* 2013). Contemporary groups were formed based on the interaction between herd, year and season of calving (HYS). To ensure well-linked edited data for variance component estimation, the sires and daughters in the HYS contemporary groups were selected in accordance to Mostert *et al.* (2010). Hence, a subset of data from Appendix 4 was created (Table 4.3) which included sires with a minimum of five daughters in at least three HYS and HYS with at least 3 cows. In addition, herd of performance and herd of birth were derived from the data as cows tend to move from where they are born to where they eventually spend their productive life.

4.2.2.1. Calculation of 305-day milk yield for Kenya and Zimbabwe

Cows with six or more test-days (Bilal and Khan, 2009) were included in calculating 305-day milk yield. In order to determine 305-day milk yield from test-day records from Kenya and Zimbabwe, the test interval method was used applying equation [3] as recommended by the International Committee on Animal Recording (ICAR, 2003).

$$\boldsymbol{LMY = I_0M_1 + I_1\frac{M_1 + M_2}{2} + I_2\frac{M_2 + M_3}{2} + \cdots + I_{n-1}\frac{M_{n-1} + M_n}{2} + I_nM_n} \qquad [3]$$

Where;

- $\boldsymbol{LMY}$: 305-day lactation milk yield (litres)
- $\boldsymbol{M_1, M_2 \dots, M_n}$: milk yield in 24 hours on the recording day (kg)
- $\boldsymbol{I_1, I_2 \dots, I_{n-1}}$: intervals between recording dates (days)
- $\boldsymbol{I_0}$: interval between the lactation period start date and the first recording date (days)
- $\boldsymbol{I_n}$: interval between the last recording date and the 305th lactation day (days)

A description of edited data from all countries for both breeds and all traits is in Tables 4.3 and 4.4. These datasets were used in the ensuing analyses.

4.2.2.2. Evaluation of fixed effects

Analysis of variance was carried out to evaluate the effects of various environmental factors including age at calving, herd of cow birth ($\boldsymbol{Herd_j}$), lactation number (1 to 5), herd-year-season of calving ($\boldsymbol{HYS_k}$) on 305-day milk yield. The $\boldsymbol{Herd_j}$ accounted for high level of movement of heifers and management differences from herds where they are born while $\boldsymbol{HYS_k}$ contemporary group accounted for where they are reared and eventually performed in. A repeat analysis assessed the impact of all these factors minus lactation number of 305-day milk yield in first lactation only. Again, the impact of the same effects on age at first calving (AFC) and interval between first and second calving (CI1) was also tested, minus lactation number (both) and age at first calving as a fixed effect when analysing AFC records. Ages at first calving records were log transformed to ensure normal distribution of data. These analyses were conducted within country and breed. A Wald test was used to assess significance.

4.2.3. Pedigree description

The software programme CFC (Co-ancestry, inbreeding and contribution) (Sargolzaei *et al*., 2006) was used to determine pedigree structure and generation intervals using animal and pedigree records available. Estimates for inbreeding coefficients were computed using pedigree from the two breeds utilising the CFC programme. Table 4.2 shows pedigree structure for both breeds from the three countries (Kenya, South Africa and Zimbabwe). Numbers of generation were highest in Holstein-Friesian and Jersey breeds for South Africa followed by Zimbabwe and Kenya. This was due to larger number of animal identities present in the South Africa pedigrees compared to the other two countries.

Table 4.2: Pedigree structure of Holstein-Friesian and Jersey cattle in Kenya, South Africa and Zimbabwe.

Details	Kenya		South Africa		Zimbabwe
	Holstein-Friesian	Jersey	Holstein-Friesian	Jersey	Holstein-Friesian
Number of animal identities	6,305	1,721	1,069,714	509,515	78,024
Number of animals in base generation identified	2,175	837	212,787	91,085	19,699
Number of identified sires	1,033	400	15,155	9,962	2,497
Number of identified sires of sires	1	1	3,209	2002	211
Number of identified dams of sires	1	1	10,681	6,673	370
Number of identified dams	2,533	736	121,043	238,865	40,288
Numbers of identified sires of dams	690	222	11,595	7,945	1,994
Number of identified dams of dams	992	254	241,222	129,367	18,521
Number of identified full sibs	39	11	21,506	14,852	1,693
Number of identified non-related individuals	4,130	884	856,927	418,430	58,325
Number of generations in pedigree	11	9	28	23	17

Among the three countries, proportion of animals with missing ancestors within Kenya was (9% for Holstein-Friesian and 13% for Jersey), in South Africa (5% for Holstein-Friesian and 4% for Jersey) and 30% for Holstein-Friesian in Zimbabwe. Pedigree data from the three countries were useful in providing relevant information on the level of connectedness and pedigree links among countries.

4.2.4. Common sires between Kenya, South Africa and Zimbabwe

Common sires were defined as those with daughters with records in two or more countries. Of these bulls, 22 Holstein-Friesian sires were common between South Africa and Zimbabwe, 3 sires were common to Kenya and South Africa and another 3 to Kenya and Zimbabwe. On average, the number of daughters of common sires per country pair was 25 (South Africa and Zimbabwe), 6 (Kenya and South Africa) and 6 daughters (Kenya and Zimbabwe), respectively. Additional genetic links were determined between country pairs and across the three countries by looking at common ancestors across seven generations. Within country, there were 103, 505 and 236 Holstein-Friesian sires with daughters with records in Kenya, South Africa and Zimbabwe, respectively.

For the Jersey breed, there was 1 sire common to Kenya and South Africa. Within country, there were 35 and 771 sires of daughters with records in Kenya and South Africa, respectively. Genetic links were determined across the two countries for seven generations. In each case, the amount of genetic links was determined by counting common sires with daughters in multiple countries and number of common ancestors for seven generations.

4.2.5. Variance component and genetic parameter estimation

Following evaluation of fixed effects, an individual animal model [4] was built to analyse 305-day milk yield in five lactations:

$$\boldsymbol{Y_{ijkl} = Herd_j + HYS_k + c_i(age) + animal_l + pe_l + e_{ijkl}} \qquad [4]$$

Where;

- $\boldsymbol{Y_{ijkl}}$: observation of animal *l* in lactation *i*
- $\boldsymbol{Herd_j}$: fixed effect of herd of birth *j* of cow *l*
- $\boldsymbol{HYS_k}$: fixed effect of herd of performance by year and season of calving *k* of cow *l* (contemporary group)

- $c_i(age)$: fixed regression on calving age of animal *l* nested within lactation number c_i
- $animal_l$: random animal genetic effect of cow *l* including animal pedigree
- pe_l : random permanent environment effect of cow *l*
- e_{ijkl} : random error term

First lactation 305-day milk yield was analysed with a model similar to model [4] after removing the effect of lactation number and permanent environment. Reproduction traits (AFC and CI1) were analysed with the same model as in first lactation 305-day milk yield; calving age was also removed from the analysis of AFC.

In the first instance, each trait was analysed separately within country and breed. In the case of Jersey breed in Kenya, herd of performance was not included in the contemporary group. This was because all first lactation cows were raised in one single herd. This was also applicable to the analysis of the two early reproduction traits (AFC and CI1). Subsequently, production and early reproduction traits were analysed jointly in bivariate analyses using the models described above. The univariate analysis of variance component estimates were used as starting values for co-variance components in the bivariate analyses. Finally, data were pooled across-country but within breed and analysed with the same models including country as an additional fixed effect.

4.2.6. Bivariate model structure

Variance and covariance components from within and across-country analyses were obtained using ASReml software (Gilmour *et al.,* 2009). The univariate variance components estimates were used as starting values for the R (residual) and G (genetic) structures in the bivariate model so as to ensure fast convergence. The (co) variance matrix for the bivariate model fitted was;

Where;

G = $\begin{pmatrix} \boldsymbol{G11} & \boldsymbol{G12} \\ \boldsymbol{G21} & \boldsymbol{G22} \end{pmatrix}$ is the genetic covariance matrix, *[5]*

R*e*= $\begin{pmatrix} \boldsymbol{R11} & \boldsymbol{R12} \\ \boldsymbol{R21} & \boldsymbol{R22} \end{pmatrix}$ is the residual covariance matrix

Trait heritability and repeatability, and genetic correlations between traits were obtained from these (co) variance components.

4.2.7. Estimated Breeding Values (EBVs) and genetic evaluation

Solutions for the random animal effect in the models described above constituted estimated breeding values (EBVs) of individual animals for the respective traits. EBVs of sires with daughters with records in the datasets were also derived through pedigree relationships. Sire EBV reliability was computed as a function of predictor error variance for each sire and genetic variance of each trait. These calculations were carried out for all traits and all sires both within- and across-country.

Pearson's correlations between sire EBVs produced within- and across-country were computed to assess consistency of the different evaluations. Furthermore, Pearson's correlations between EBVs of sires with daughters in multiple countries were calculated (Sedgwick, 2012). These correlations were adjusted for sire EBV reliability (Montaldo and Pelcastre-Cruz, 2012) to derive approximate estimates of genetic correlation between countries. The following formula was used:

$$r_G = \frac{r_o}{\sqrt{arel_i + arel_j}} \qquad [6]$$

Where;

r_G : approximate genetic correlation of sires

r_o : correlation between sire EBVs in the two countries

$arel_i$: average reliability of sires in country 1

$arel_j$: average reliability of sires in country 2

Sire EBVs were also averaged by year of birth of sire in order to estimate genetic trends by breed, trait and country.

4.3. RESULTS

4.3.1. Edited data description

4.3.1.1. Holstein-Friesian Breed

Table 4.3 shows subset structure of edited data used for estimation of variance components, genetic parameters and EBVs in the Holstein-Friesian breed.

Table 4.3: Edited Holstein-Friesian data by country; averages are followed by standard deviation.

	Country		
	Kenya	South Africa	Zimbabwe
Number of lactation records	2,333	25,208	5,929
Number of cows with records	1,058	12,384	3,738
Number of sires of cows	103	505	236
Average number of daughters per sire	10	25	16
Number of dams of cows	630	10,954	3,209
Number of calving herds	62	266	40
Average 305-day milk yield (Litres)	5,287 (1,578)	8,787 (2,587)	2,868 (909)
Average age at first calving (days)	972.0 (123.1)	873.0 (114.2)	873.0 (105.4)
Average CI1 (days)	475.3 (199.0)	429.5 (95.0)	493.8 (151.7)

Coefficient of variation for 305-day milk yield was lowest in South Africa (CV% = 29%) compared to Kenya (CV = 30%) and Zimbabwe (32%). For age at first calving, CV% in Kenya and South Africa were the same (13%) and 12% for Zimbabwe. Cows calved for the first time at a much older age in Kenya than in South Africa and Zimbabwe (972 vs. 873 days). Coefficient of variation for CI1 was lowest in South Africa (CV% = 22%) compared to Zimbabwe (CV% = 31%) and Kenya (CV% = 42%).

4.3.1.2. Jersey Breed

Table 4.4 presents the edited structure of data from Jersey breeds that were used in the genetic analysis.

Table 4.4: Edited Jersey data structure by country; averages are followed by standard deviation.

	Country	
	Kenya	South Africa
Number of lactation records	898	65,134
Number of cows with records	332	26,374
Number of sires of cows	35	771
Average number of daughters per sire	10	34
Number of dams of cows	293	20,740
Number of calving herds	3	240
Average 305-day milk yield (Litres)	4,623 (1,153)	5,563 (1,411)
Average age at first calving (days)	909.0 (153.0)	861.0 (129.0)
Average CI1 (days)	457.4 (148.4)	405.3 (92.4)

Jersey cows in South Africa calved for the first time at a younger age and produced more milk than cows in Kenya. However, coefficient of variation in 305-day milk yield in within Kenya and South Africa was the same (25%). Coefficients of variation for early reproduction traits were lower in South Africa (AFC = 15%; CI1 = 23%) compared to Kenya (AFC = 17%; CI1 = 33%).

4.3.2. Inbreeding coefficient

Table 4.5 shows results of inbreeding analysis for the two breeds in the three countries.

Table 4.5: Inbreeding estimates Holstein-Friesian and Jersey cows in Kenya, South Africa and Zimbabwe.

	Kenya		South Africa		Zimbabwe
	Holstein-Friesian	Jersey	Holstein-Friesian	Jersey	Holstein-Friesian
Average inbreeding coefficient (all animals)	0.001	0.0002	0.01	0.01	0.002
Average inbreeding coefficient (inbred animals only)	0.22	0.25	0.02	0.03	0.05
Maximum inbreeding coefficient	0.25	0.25	0.41	0.42	0.38

Number of inbred individuals	15	2	434,916	225,895	3,558

When Holstein-Friesian data were jointly analysed across the three countries, inbreeding coefficient for all animals, inbreeding coefficient for inbred animals and maximum inbreeding coefficient were 0.005, 0.02 and 0.41, respectively. Minimum and maximum family sizes were 2 and 8, respectively and number of full sib groups was 773. Across the two countries for the Jersey breed, inbreeding levels were 0.01 across all animals, 0.03 for inbred animals and 0.37 as the maximum inbreeding coefficient. Minimum and maximum family sizes were 2 and 9, respectively and the number of full sibs was 1,388. Results for Kenya reflected poor pedigree structure due to much missing data.

4.3.3. Common sires and genetic links across country

4.3.3.1. Holstein-Friesian breed

Holstein-Friesian sires have been used for pure- and cross-breeding across the three countries. Table 4.6 shows the sires that were common in country pairs and across the three countries considering both maternal and paternal gene-flow over seven generations.

Table 4.6: Number of common Holstein-Friesian sires with daughters in multiple countries (1st generation) and number of common ancestors (2nd and higher generations).

	Country pairs			
Generation	Kenya-South Africa	Kenya-Zimbabwe	South Africa-Zimbabwe	Across 3 countries
1st generation (sires with daughters with data)	3	3	22	-
2nd generation	16	9	37	9
3rd generation	5	5	18	5
4th generation	3	5	11	5
5th generation	5	4	3	3
6th generation	4	4	3	3
7th generation	4	3	3	3
Total common sires	40	33	97	28

Despite the relatively limited number of direct links (number of sires with daughters performing in multiple countries) there were substantial additional links through common ancestors. This implies that there has been trade and importation of sires for genetic improvement from several regions around the world. Most common sires were from United States of America followed by Canada, The Netherlands, the United Kingdom, Australia and New Zealand.

4.3.3.2. Jersey breed

There were 31 common Jersey sires across the ancestry used for either pure- or cross-breeding in Kenya and South Africa. This implies a more limited number in the population size. Table 4.7 shows the sires that were common in the two countries including both maternal and paternal gene-flow for six generations.

Table 4.7: Number of common Jersey sires with daughters in two countries (1st generation) and number of common ancestors (2nd and higher generations).

	Country		
Generation	Kenya	South Africa	Common
1st generation (sires with daughters with data)	35	771	1
2nd generation	21	28	15
3rd generation	14	80	12
4th generation	1	14	1
5th generation	1	10	1
6th generation	1	8	1
Total common sires	73	911	31

Across the ancestry, the most common sire numbers were in South Africa than in Kenya. Majority of the sires were from the USA, Canada and New Zealand.

4.3.4. Phenotypic data analysis and trends

4.3.4.1. Holstein-Friesian breed

Parity, age at first calving, country, herd-year-season of calving ($\boldsymbol{HYS}$) interaction and herd of birth ($\boldsymbol{Herd}$) significantly affected 305-day milk yield, age at first calving and first calving interval (p<0.05). The growth environment ($\boldsymbol{Herd}$ and $\boldsymbol{HYS}$) was shown to have a significant effect on both production and reproduction traits measured (P<0.05). The impact of drought, poor management systems and rapid cow movement between herd addresses and locations imparted on the general performance and productivity of cows. Table 4.8 shows genetic traits and fixed effects for the analyses applied to the Holstein-Friesian breed.

Table 4.8: Holstein-Friesian breed summary of model analysis shown as traits in rows and factors in columns.

Traits	Factors (Fixed effects)
305-day milk yield in five lactations (Litres)	$Herd$, HYS, lactation number, and age at calving
305-day milk yield in first lactation (Litres)	$Herd$, HYS, and age at first calving
Age at first calving (days)	$Herd$ and HYS
CI1 (days)	$Herd$, HYS, and age at first calving

Footnotes: $Herd$ (herd of cow birth); HYS (herd-year-season of calving); CI (interval between first and second calving).

Milk yield changed over the years in all three countries (Figure 4.1). A general flat trend could be seen in all three countries even though South Africa had the highest average for 305-day milk yield. Milk yield decreased in South Africa in 2002 and again in 2007, and peaked from 2008. There was a decline in milk yield between 2000 and 2001 in Zimbabwe. In Kenya, the trend was shown to be almost the same as zero while in Zimbabwe the trend increased from 2008. Fluctuations in the trends may have been due to changes in management systems in terms of availability of feed resources and cows management.

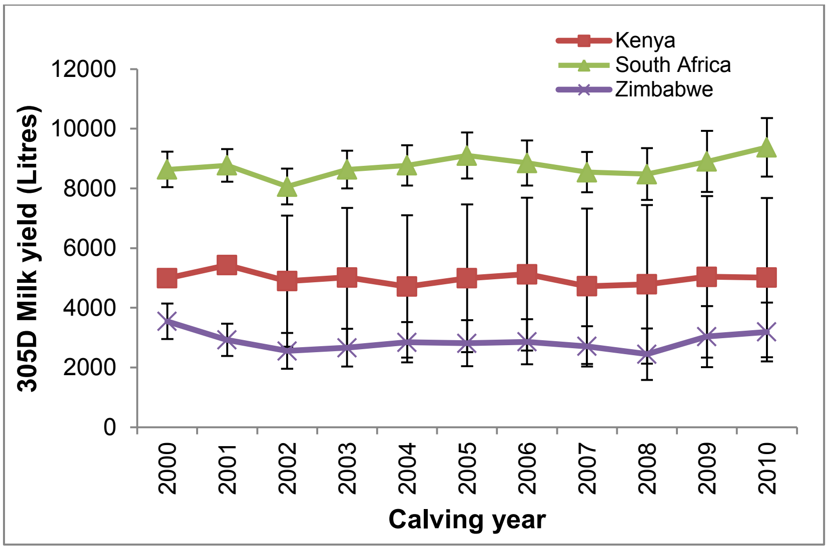

Figure 4.1: Phenotypic trend of 305-day milk yield (means and standard deviations shown as error bars over five lactations) for Holstein-Friesian cows in Kenya, South Africa and Zimbabwe.

Similar trends were seen for 305-day milk yield in first lactation for the Holstein-Friesian breed in the three countries. There was a decline in milk yield in South Africa between 2002 till 2007 and an improvement from 2008. Figure 4.2 illustrates phenotypic trend in 305-day milk yield in first lactation.

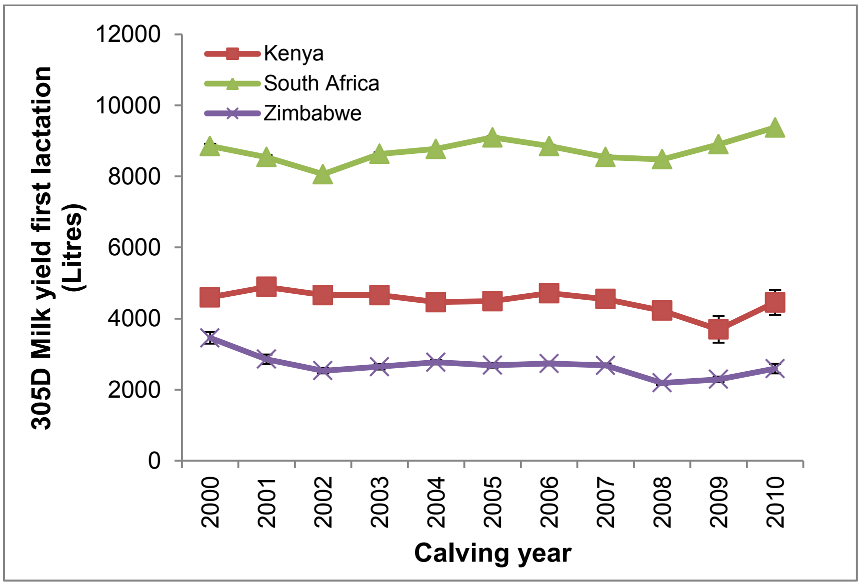

Figure 4.2: Phenotypic trend of 305-day milk yield (means and standard deviations shown as error bars in first lactation) for Holstein-Friesian cows in Kenya, South Africa and Zimbabwe.

Figure 4.3 shows phenotypic trend in age at first calving in Holstein-Friesian cows calving over a 10-year period (2000-2010). In Kenya, this trend gradually changed over the years but had a sharp increase from 2008. Zimbabwe showed a slight increase over the years and South Africa maintained a steady and desirable trend in age at first calving over 10 calving years. Increased age and wide error bars in Kenya may have been due to varying effects of management practices such as poor feeding regimen, poor herd health, and inadequate genetic improvement techniques occurring within country.

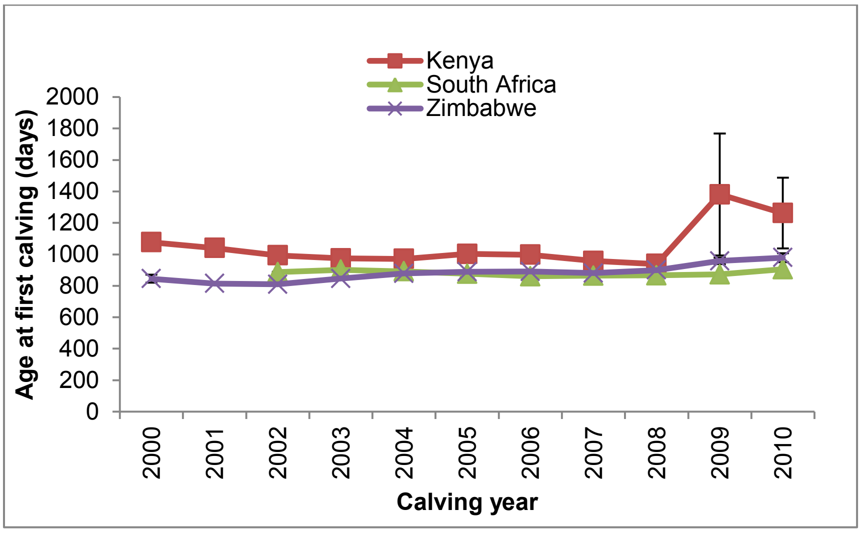

Figure 4.3: Phenotypic trend of age at first calving (means and standard deviations shown as error bars) for Holstein-Friesian cows in Kenya, South Africa and Zimbabwe.

Figure 4.4 below shows phenotypic trend in interval between first and second calving in the Holstein-Friesians calving over the 10-year period (2000-2010). Trends in Zimbabwe and Kenya showed a sharp increase while in South Africa the trend was steady and calving interval was the shortest among the three countries.

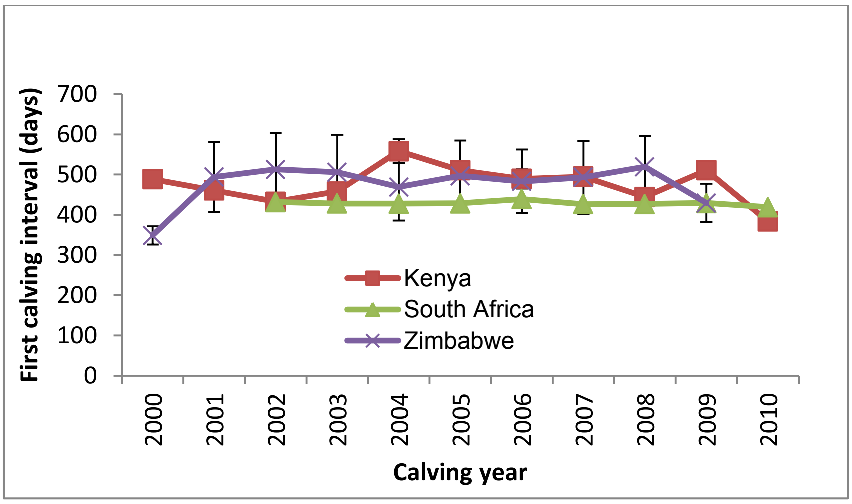

Figure 4.4: Phenotypic trend in interval between first and second calving (means and standard deviations shown as error bars) for Holstein-Friesian cows in Kenya, South Africa and Zimbabwe.

4.3.4.2. Jersey breed

Parity, age at calving, country, year-season of calving $\boldsymbol{YS}$ interactions within Kenya and herd-year-season of calving $\boldsymbol{HYS}$ in South Africa significantly affected milk yield and reproduction traits (P<0.05). Also, $\boldsymbol{Herd}$ and $\boldsymbol{HYS}$ in the across-country analyses significantly affected milk yield (p<0.05). Table 4.9 shows genetic traits and fixed effects for the analyses applied to the Jersey breed.

Table 4.9: Jersey breed summary of model analysis shown as traits in rows and factors in columns.

Traits	Factors (Fixed effects) for Kenya	Factors (Fixed effects) for South Africa
305-day milk yield in five lactation (Litres)	$Herd$, HYS, lactation number, age at calving	$Herd$, HYS, lactation number, age at calving
305-day milk yield in first lactation (Litres)	$Herd$, YS, age at first calving	$Herd$, HYS, age at first calving
Age at first calving (days)	$Herd$ and YS	$Herd$ and HYS
CI1 (days)	$Herd$, YS, and age at first calving	$Herd$, HYS, and age at first calving

Footnotes: $Herd$ (herd of cow birth); HYS (herd-year-season of calving); YS (year-season of calving); CI (interval between first and second calving).

The 305-day milk yield in five lactations changed over the years within the two countries (Figure 4.5). Figure 4.5 shows trend in milk yield in Jersey cows in Kenya and South Africa performing over a 10-year period.

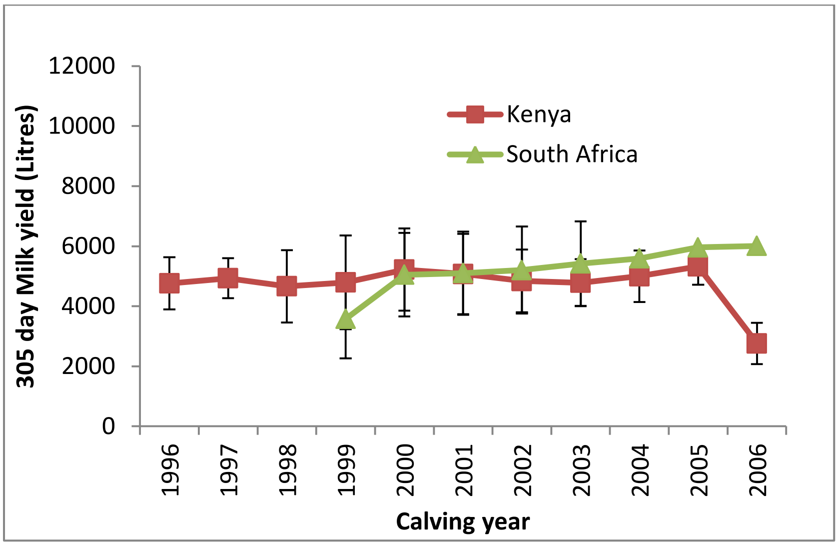

Figure 4.5: Phenotypic trend of 305-day milk yield (means and standard deviations shown as error bars over five lactations) for Jersey cows in Kenya and South Africa (1996-2006).

Phenotypic trend in 305-day milk yield in five lactations in South Africa was higher compared to Kenya. Declines in 305-day milk yield trend in Kenya were seen in 1998 and 2006 which was due to the effects of drought resulting in fewer cows in calving periods.

Trend in age at first calving changed over the 10-year period and was more stable within South Africa than in Kenya (Figure 4.6). Age at first calving gradually decreased over the years with an increase in 2000 and 2005 due to impact of higher calving age of some cows at 1,080 days from South Africa while in Kenya it was 840 days. This was due to effect on management systems whereby Jersey cows attained age at first calving at a longer time.

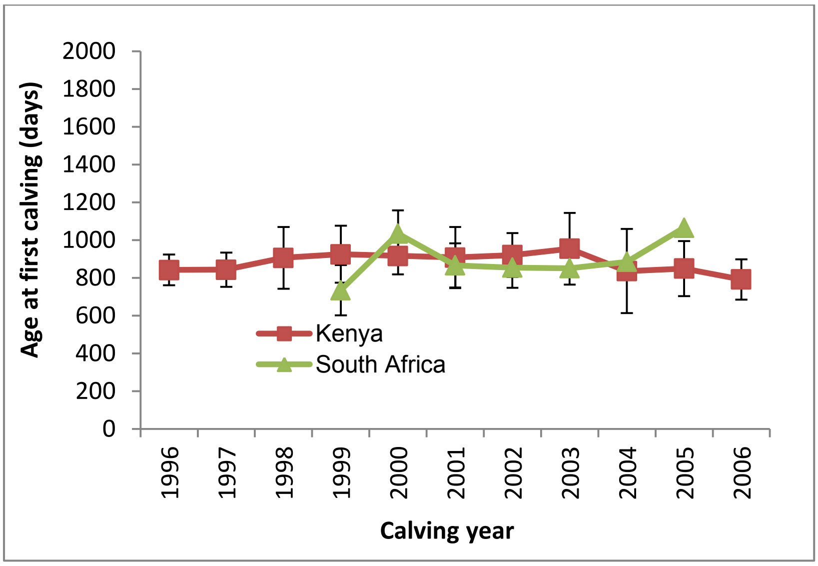

Figure 4.6: Phenotypic trend in age at first calving (means and standard deviations shown as error bars) in Jersey cows performing within Kenya and South Africa (1996-2006).

Phenotypic trend in interval between first and second calving also changed over the years within Kenya and South Africa (Figure 4.7). Trend was consistent in South Africa which may have been imparted by a stable farm management system than that in Kenya. Average interval between first and second calving across Kenya and South Africa was 431.4±120.40 days.

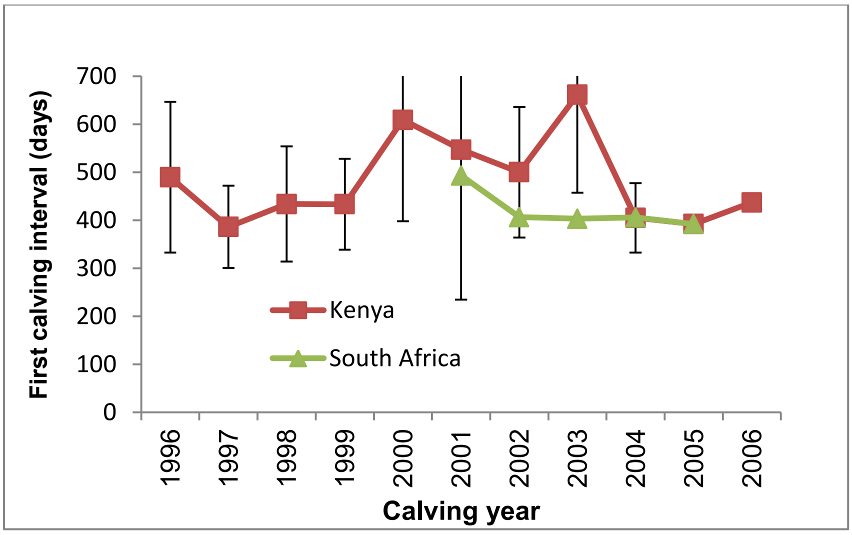

Figure 4.7: Phenotypic trend in interval between first and second calving (CI1) (means and standard deviations shown as error bars) in Jersey cows performing between years 1996 and 2006 in Kenya and South Africa.

Phenotypic trend in interval between first and second calving gradually changed over the years within the two countries. South Africa decreased from 2001 maintained a stable trend from 2002. Trend within Kenya peaked from 2000 and was highest in 2003. These peaks may have been due to changes in farm management systems whereby cows had longer lactation periods and their inability to attain second calving within a short time.

4.3.5. Variance component estimates within and across country

4.3.5.1. Holstein-Friesian Breed

Variance component estimates for milk production and reproduction traits within and across country are summarised in Table 4.10. In some cases it was not possible to properly de-compose the total phenotypic variance within country (all traits in Kenya and CI1 in Zimbabwe) leading to genetic variance estimates that was either non-significantly different from zero or non-attainable. However, all variance components were estimable in the across-country analyses.

Table 4.10: Genetic, phenotypic and residual variance estimates for milk production and reproduction traits from within and across country analyses for Holstein-Friesian cattle; estimates are followed by standard errors.

Traits	Kenya	South Africa	Zimbabwe	Across country
305-day Milk yield (σ^2_g)	158,663 (93,941) $^{\alpha}$	190,278 (29,059)*	65,042 (15,117)*	178,992 (22,598)*
305-day Milk yield (σ^2_{pe})	382,288 (96,294)*	431,861 (27,420)*	27,471 (16,650)*	313,457 (21,573)*
305-day Milk yield (σ^2_e)	1,041,190 (44,382)*	964,397 (12,479)*	509,451 (15,186)*	1,140,150 (12,229)*
305-day Milk yield (σ^2_p)	1,582,141 (57,079)*	1,586,500 (17,087)*	601,680 (11,730)*	1,632,600 (14,196)*
First lactation 305-day milk yield (σ^2_g)	394,726 (195,408) $^{\alpha}$	159,019 (28,550)*	28,500 (14,467)*	203,213 (25,626)*
First lactation 305-day milk yield (σ^2_e)	1,008,530 (180,740)*	1,049,210 (27,690)*	431,803 (16955)*	1,024,950 (23,836)*
First lactation 305-day milk yield (σ^2_p)	1,400,000 (85,177)*	1,210,000 (17,347)*	460,000 (11,827)*	1,230,000 (14,582)*
AFC (σ^2_g)	542 (3,873) $^{\alpha}$	1,008 (203)*	725 (259)*	1,426 (200)*
AFC (σ^2_e)	42,131 (4,550)*	5,313 (184)*	6,512 (276)*	6,982 (180)*
AFC (σ^2_p)	42,673 (2,599)*	6,321 (99)*	7,237 (184)*	8,408 (101)*
CI1 (σ^2_g)	7,351 (8,353) $^{\alpha}$	174 (84)*	179 (641) $^{\alpha}$	531 (142)*
CI1 (σ^2_e)	26,382 (8,019)*	7,757 (131)*	20,313 (878)*	10,270 (174)*
CI1 (σ^2_p)	33,733 (2,998)*	7,931 (110)*	20,493 (639)*	10,802 (128)*

Footnotes: σ^2_g (genetic variance); σ^2_e (residual variance); σ^2_{pe} (permanent environmental variance); σ^2_p (phenotypic variance); significantly different from zero *(P<0.05); $^{\alpha}$ not significantly different from zero (P> 0.05); AFC (Age at first calving); CI1 (Interval between first and second calving).

4.3.5.2. Jersey Breed

Table 4.11 shows variance component estimates from within and across-country analyses of Jersey cow data. Genetic variance estimates within Kenya were either not different from zero or non-attainable. It was also not possible to properly de-compose the total phenotypic variance within-country for age at first calving in South Africa and in the across-country data analysis. Within South Africa and across-country analyses yielded similar results as data in the latter were dominated by data from South Africa.

Table 4.11: Genetic, phenotypic and residual variance estimates for milk production and reproduction traits from within and across country analyses of Jersey cattle; estimates are followed by standard errors.

Traits	Kenya	South Africa	Across country
305-day Milk yield (σ^2_g)	34,801 (53,725) $^{\alpha}$	159,725 (12,829)*	167,492 (13,112)*
305-day Milk yield (σ^2_{pe})	203,837 (68,402)*	233,469 (10,409)*	198,952 (10,616)*
305-day Milk yield (σ^2_e)	760,850 (49,214)*	463,637 (3,472)*	595,622 (419)*
305-day Milk yield (σ^2_p)	999,490 (54,553)*	856,830 (6,632)*	962,070 (6,891)*
First lactation 305-day milk yield (σ^2_g)	Non-estimable	139,317 (19,960)*	168,028 (20,617)*
First lactation 305-day milk yield (σ^2_e)	Non-estimable	363,992 (162)*	398,598 (16,531)*
First lactation 305-day milk yield (σ^2_p)	Non-estimable	503,310 (8,660)*	567,390 (8,940)*
AFC (σ^2_g)	Non-estimable	107 (8,534) $^{\alpha}$	92 (88) $^{\alpha}$
AFC (σ^2_e)	Non-estimable	5,109 (412)*	8,660 (139)*
AFC (σ^2_p)	Non-estimable	9,593 (195)*	8,752 (116)*
CI1 (σ^2_g)	Non-estimable	239 (119)*	319 (133)*
CI1 (σ^2_e)	Non-estimable	6,349 (150)*	7,571 (163)*
CI1 (σ^2_p)	Non-estimable	6,588 (116)*	7,890 (124)

Footnotes: σ^2_g (genetic variance); σ^2_e (residual variance); σ^2_{pe} (permanent environmental variance); σ^2_p (phenotypic variance); significantly different from zero *(P<0.05); $^{\alpha}$ not significantly different from zero (P> 0.05); AFC (Age at first calving); CI1 (Interval between first and second calving).

As expected, genetic variance components tended to be more precise with across-country genetic analyses than within-country for both breeds.

4.3.6. Genetic parameter estimates within and across country

4.3.6.1. Holstein-Friesian breed

Genetic parameter estimates for milk production and reproduction traits derived from variance component estimates (Table 4.10) are shown in Table 4.12 for Holstein-Friesians. Consistently with variance components, genetic parameters were not always statistically significant or estimable in within-country analyses. Estimates were significantly different from zero ($P<0.05$) for all traits in the joint analyses across the three countries. These latter analyses yielded the most accurate results as exemplified by the smaller standard errors compared to within-country estimates. In general, the estimates for within and across-country genetic parameters varied within and across milk production and reproduction traits for the three countries. Also, estimates of heritability improved and were associated with smaller standard errors in across-country evaluations compared to within-country analyses. Genetic correlations between milk production and reproduction traits were not significant within country and in across-country evaluations for Kenya and Zimbabwe. This is because data structure for Kenya and Zimbabwe were very limited compared to South Africa. There were fewer numbers of records following data edits for Kenya and Zimbabwe.

Table 4.12: Within and across country genetic parameters for Holstein-Friesians; estimates are followed by standard errors.

Traits	Kenya	South Africa	Zimbabwe	Across country
h^2 of 305-day milk yield in five lactations (MY)	0.100 (0.059) $^{\alpha}$	0.119 (0.017)*	0.108 (0.025)*	0.111 (0.014)*
h^2 of First lactation 305-day milk yield (L1)	0.249 (0.134) $^{\alpha}$	0.132 (0.023)*	0.062 (0.031)*	0.165 (0.020)*
h^2 of AFC	0.186 (0.124) $^{\alpha}$	0.159 (0.031)*	0.100 (0.035)*	0.168 (0.023)*
h^2 of CI1	0.244 (0.249) $^{\alpha}$	0.023 (0.011)*	0.009 (0.031) $^{\alpha}$	0.049 (0.013)*
R for MY	0.340 (0.03)*	0.392 (0.008)*	0.154 (0.022)*	0.302 (0.007)*
Genetic correlation (MY & AFC)	Non-estimable	-0.007 (0.371) $^{\alpha}$	Non-estimable	Non-estimable
Phenotypic correlation (MY & AFC)	-0.065 (0.031)*	0.536 (0.005)*	0.060 (0.017)*	0.329 (0.007)*
Residual correlation (MY & AFC)	Non-estimable	0.615 (0.005)*	Non-estimable	Non-estimable
Genetic correlation (MY & CI1)	Non-estimable	0.466 (0.120)*	Non-estimable	0.314 (0.104)*
Phenotypic correlation (MY & CI1)	0.081 (0.062) $^{\alpha}$	0.118 (0.010)*	0.034 (0.024)*	0.099 (0.009)*
Residual correlation (MY & CI1)	Non-estimable	0.111 (0.013)*	Non-estimable	0.095 (0.012)*
Genetic correlation (L1 & AFC)	Non-estimable	-0.131 (0.116) $^{\alpha}$	-0.377 (0.154)*	-0.176 (0.095) $^{\alpha}$
Phenotypic correlation (L1 & AFC)	0.049 (0.043) $^{\alpha}$	0.202 (0.009)*	0.002 (0.021) $^{\alpha}$	0.159 (0.008)*
Residual correlation (L1 & AFC)	Non-estimable	0.261 (0.019)*	0.131 (0.045)*	0.226 (0.017)*
Genetic correlation (L1 & CI1)	Non-estimable	0.599 (0.123)*	Non-estimable	0.511 (0.113)*
Phenotypic correlation (L1 & CI1)	0.069 (0.061) $^{\alpha}$	0.104 (0.009)*	0.043 (0.023)*	0.095 (0.008)*
Residual correlation (L1 & CI1)	Non-estimable	0.058 (0.015)*	Non-estimable	0.053 (0.014)*
Genetic correlation (AFC & CI1)	Non-estimable	-0.165 (0.161) $^{\alpha}$	-0.563 (0.187)*	-0.801 (0.039)*
Phenotypic correlation (AFC & CI1)	-0.010 (0.077) $^{\alpha}$	-0.022 (0.009)*	-0.285 (0.020)*	-0.211 (0.009)*
Residual correlation (AFC & CI1)	Non-estimable	-0.008 (0.017) $^{\alpha}$	-0.242 (0.033)*	0.061 (0.024)*

Footnotes: h^2 (Heritability), R (Repeatability), MY (305-day milk yield in five lactations); L1 (305-day milk yield in first lactation); AFC (Age at first calving); CI1 (Interval between first and second calving); significantly different from zero *(P<0.05); $^{\alpha}$ not significantly different from zero (P> 0.05).

In general, these results highlight the feasibility of pooling data for across-country genetic evaluations.

4.3.6.2. Jersey Breed

Genetic parameter estimates from milk production and reproduction traits derived from variance component estimates (Table 4.11) are shown in Table 4.13 for Jerseys. Across-country analysis improved genetic estimates than within-country estimates with the evidence of smaller standard errors.

Table 4.13: Within and across country genetic parameters for Jerseys; estimates are followed by standard errors.

Genetic parameters	Kenya	South Africa	Across country
h^2 of 305-day milk yield in five lactations (MY)	0.035 (0.054) $^{\alpha}$	0.186 (0.014)*	0.174 (0.013)*
h^2 of 305-day milk yield in first lactation (L1)	Non-estimable	0.277 (0.037)*	0.298 (0.034)*
h^2 of AFC	Non-estimable	0.010 (0.011) $^{\alpha}$	0.011 (0.010) $^{\alpha}$
h^2 of CI1	Non-estimable	0.036 (0.018)*	0.040 (0.017)*
Repeatability of MY	0.239 (0.044)*	0.459 (0.005)*	0.381 (0.005)*
Genetic correlation (MY & AFC)	Non-estimable	Non-estimable	Non-estimable
Phenotypic correlation (MY & AFC)	0.108 (0.046)*	0.370 (0.004)*	0.366 (0.004)*
Residual correlation (MY & AFC)	Non-estimable	Non-estimable	Non-estimable
Genetic correlation (MY & CI1)	Non-estimable	0.267 (0.112)*	0.317 (0.115)*
Phenotypic correlation(MY & CI1)	0.159 (0.097) $^{\alpha}$	0.107 (0.013)*	0.105 (0.013)*
Residual correlation (MY & CI1)	Non-estimable	0.110 (0.014)*	0.103 (0.014)*
Genetic correlation (L1 & AFC)	Non-estimable	-0.098 (0.272) $^{\alpha}$	-0.138 (0.284) $^{\alpha}$
Phenotypic correlation (L1 & AFC)	0.025 (0.072) $^{\alpha}$	0.234 (0.009)*	0.226 (0.009)*
Residual correlation (L1 & AFC)	Non-estimable	0.285 (0.018)*	0.277 (0.018)*
Genetic correlation (L1 & CI1)	Non-estimable	0.319 (0.169) $^{\alpha}$	0.353 (0.177)*
Phenotypic correlation (L1 & CI1)	0.023 (0.093) $^{\alpha}$	0.089 (0.012)*	0.075 (0.012)*
Residual correlation (L1 & CI1)	Non-estimable	0.064 (0.023)*	0.045 (0.022)*
Genetic correlation (AFC & CI1)	Non-estimable	0.283 (0.211) $^{\alpha}$	0.150 (0.187) $^{\alpha}$
Phenotypic correlation(AFC & CI1)	-0.039 (0.101) $^{\alpha}$	-0.049 (0.012)*	-0.035 (0.013)*
Residual correlation (AFC & CI1)	Non-estimable	-0.087 (0.022)*	-0.084 (0.033)*

Footnotes: h^2 (Heritability), R (Repeatability), MY (305-day milk yield in five lactations); L1 (305-day milk yield in first lactation); AFC (Age at first calving); CI1 (Interval between first and second calving); significantly different from zero *(P<0.05); $^{\alpha}$ not significantly different from zero (P> 0.05).

As expected, across-country genetic analysis estimates were very similar to within-country South African estimates.

4.3.7. Correlation between common sire EBVs in different countries

Pearson’s correlation between estimated breeding values (EBVs) of sires with daughters in different countries was only possible to derive for production traits in the South Africa-Zimbabwe pair that featured 22 sires common to Holstein-Friesian population.

Table 4.14 below shows approximate genetic correlation, reliability adjustments and Pearson’s correlation by trait in the 22 Holstein-Friesian sires common to South Africa and Zimbabwe.

Table 4.14: Pearson’s correlation between EBVs of the twenty-two Holstein-Friesian sires common to South Africa and Zimbabwe with approximate genetic correlations (rG) between the two countries for 305-day milk yield over five lactations and first lactation milk yield.

Measure of relationship and reliability	Over five lactations	In first lactation
EBV correlation	0.29	0.29
Reliability adjustment	0.50	0.35
Approximate rG	0.58	0.83

Reliable sire EBVs for early reproduction traits could not be derived from within Kenya and Zimbabwe analyses because genetic parameters were essentially zero. For the other country pairs in Holstein-Friesian and Jersey evaluations, numbers of common bulls were too low to repeat these calculations. Based on these estimates it was decided to treat the traits as being the same across countries.

4.3.8. Correlation between sire EBVs from within- and across-country analyses

Pearson’s correlation between EBVs of Holstein-Friesian sires from within and across-country analyses are shown in Table 4.15. These correlations could not be derived for Kenya (all traits) and Zimbabwe (CI1) because within-country sire reliabilities were practically zero due to a zero estimate of genetic variance (Table

4.10) and heritability (Table 4.12). In the other cases, medium to strong correlations were observed for both traits.

Table 4.15: Pearson's correlation between EBVs of Holstein-Friesian sires from within- and across-country analyses.

Country Sires	305D MY	First MY	AFC	CI1
Kenya	Non-estimable	Non-estimable	Non-estimable	Non-estimable
South Africa	0.78	0.87	0.58	0.83
Zimbabwe	0.74	0.81	0.90	Non-estimable

Footnotes: AFC (Age at first calving); CI1 (Interval between first and second calving).

Correlations between Jersey sire EBVs calculated within and across-country are in Table 4.16. South Africa correlations for AFC and Kenya correlations for all traits were not estimated because genetic variance (Table 4.11) and heritability estimates (Table 4.13) for these traits were not significantly different from zero.

Table 4.16: Pearson's correlation between EBVs of Jersey sires from within- and across-country analyses.

Country Sires	305D MY	First MY	AFC	CI1
Kenya	Non-estimable	Non-estimable	Non-estimable	Non-estimable
South Africa	0.98	0.93	Non-estimable	0.88

Footnotes: AFC (Age at first calving); CI1 (Interval between first and second calving).

4.3.9. Sire EBV Reliability from within and across country analyses

Reliability of sire EBVs gave a measure of precision associated with estimates of breeding values derived for both Holstein-Friesian and Jersey breeds.

4.3.9.1. Holstein-Friesian Sires

Average reliabilities of Holstein-Friesian sire EBVs for production and reproduction traits are shown in Table 4.17. Reliability for 305-day milk yield in first and in five lactations, interval between first and second calving and age at first calving in Kenya were not estimable as genetic variance and heritability were not significantly different from zero (Tables 4.10 and 4.12). The same was true for calving interval in

Zimbabwe. Otherwise, sire EBV reliability was higher in across-country than within-country genetic evaluations. This gives the opportunity to select sires more accurately in joint evaluations than within-country.

Table 4.17: Average reliability of Holstein-Friesian sire EBVs calculated within- and across-country by trait.

Details	Country of sire					
	Kenya		South Africa		Zimbabwe	
Traits	Within	Across	Within	Across	Within	Across
305-day milk yield	0.00	0.27	0.42	0.44	0.32	0.34
305-day milk yield in first lactation	0.00	0.22	0.39	0.49	0.17	0.37
AFC	0.00	0.21	0.48	0.51	0.21	0.38
CI1	0.00	0.06	0.13	0.27	0.00	0.15

Footnotes: AFC (Age at first calving); CI1 (Interval between first and second calving).

4.3.9.2. Jersey Sires

Table 4.18 shows average reliability of Jersey sire EBVs for production and reproduction traits, within-country and across-country. Reliable sire EBVs could not be obtained within Kenya for any trait because of zero genetic variance (Table 4.11) and heritability (Table 4.13) estimates. The same was true for age at first calving in the within South Africa and across-country evaluations. Otherwise, reliability of sire EBVs obtained from across-country analyses were higher than within-country.

Table 4.18: Average reliability of Jersey sire EBVs calculated within- and across-country by trait.

Details	Country of sire			
	Kenya		South Africa	
Traits	Within	Across	Within	Across
305-day milk yield	0.00	0.39	0.57	0.58
305-day milk yield in first lactation	0.00	0.29	0.40	0.45
AFC	0.00	0.02	0.00	0.03
CI1	0.00	0.04	0.14	0.17

Footnotes: Footnotes: AFC (Age at first calving); CI1 (Interval between first and second calving)

4.3.10. Genetic trends

Genetic trends were calculations based on average sire EBVs from across-country analyses by sire year of birth for all traits and breeds.

4.3.10.1. Holstein-Friesian breed

Figure 4.8 shows the genetic trend for 305-day milk yield in five lactations.

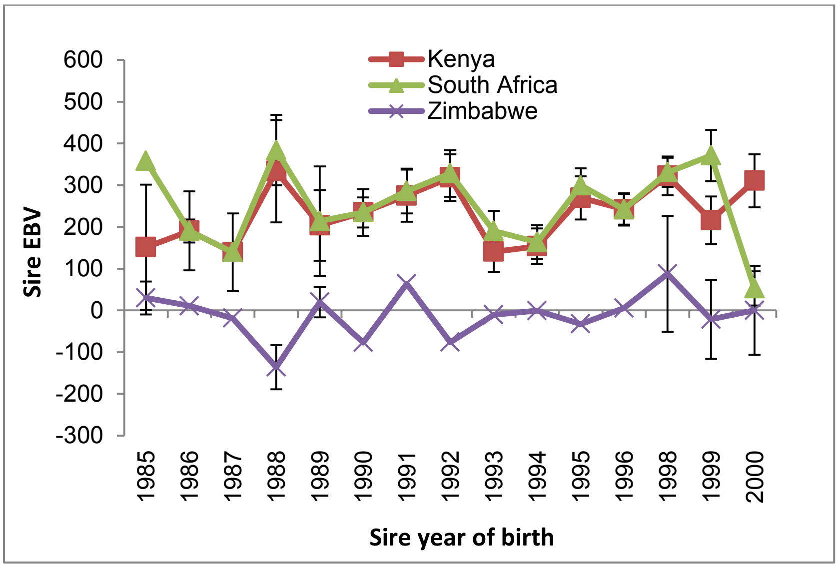

Figure 4.8: Genetic trend of Holstein-Friesian sires for 305-day milk yield (litres) from the across-country genetic evaluation by sire country of performance and birth year.

Sharp declines were seen in EBVs of sires born in 1987 and 2000 and performed in South Africa and almost the same in Zimbabwe. In general, genetic trends in milk yield in five lactations did not change over the 15-year period. A small improvement can be seen in South Africa amounting to 240.81±57.81 litres/year.

Figure 4.9 shows the genetic trend in age at first calving.

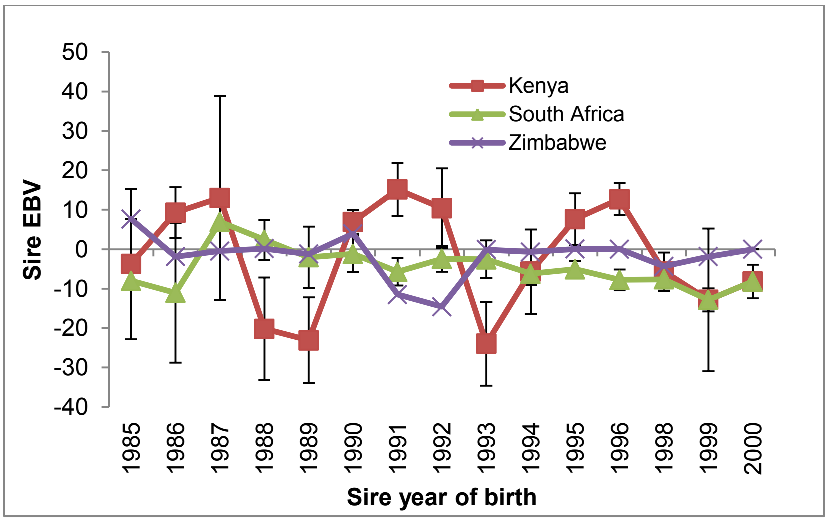

Figure 4.9: Genetic trend of Holstein-Friesian sires for age at first calving (days) from the across-country genetic evaluation by sire country of performance and birth year.

Sires performing in South Africa exhibited a desirable trend (-14.21±0.51days/year) compared to other countries.

Figure 4.10 shows genetic trends for interval between first and second calving of Holstein-Friesian sires performing in the three countries over a 15-year birth period (1985-2000). Undesirable positive trends were seen in Kenya (0.38±3.76 days) and Zimbabwe (8.55±1.05 days) compared to South Africa (-1.84±0.31 days).

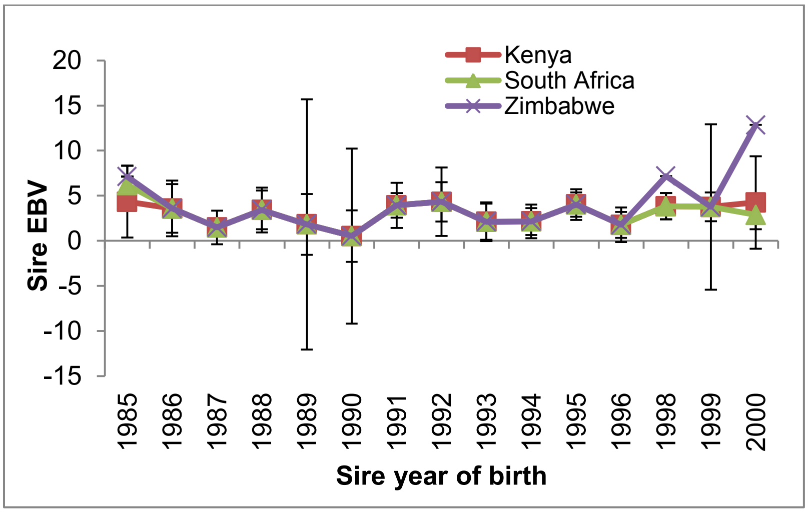

Figure 4.10: Genetic trend of Holstein-Friesian sires for first calving interval (days) from the across-country genetic evaluation by sire country of performance and birth year.

4.3.10.2. Jersey Breed

Figure 4.11 shows genetic trends in 305-day milk yield in five lactations for Jersey sires performing in Kenya and South Africa between years 1985 and 2000.

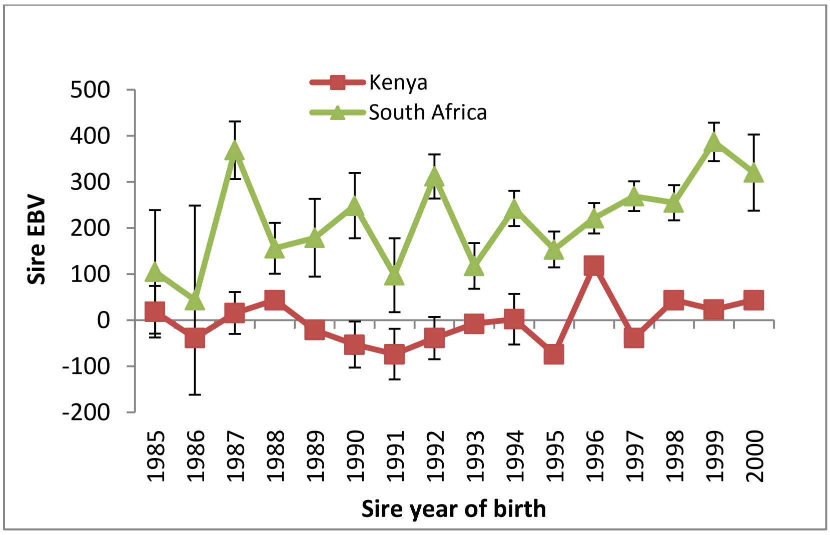

Figure 4.11: Genetic trend of Jersey sires for 305-day milk yield (litres) from the across-country genetic evaluation by sire country of performance and birth year.

Trend in South Africa (213.79±68.43litres/year) improved over the years compared to Kenya, where it was practically zero.

Figure 4.12 shows genetic trends for interval between first and second calving over a 15-year period in Kenya and South Africa.

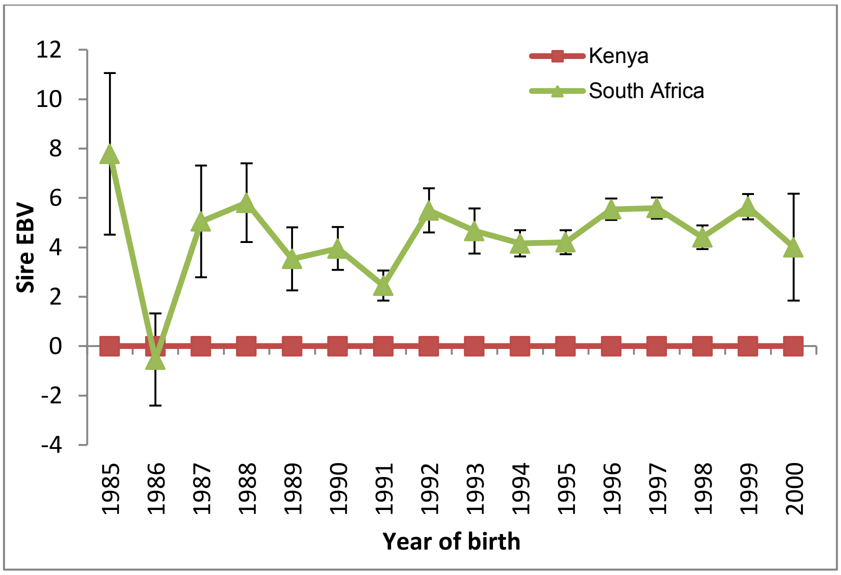

Figure 4.12: Genetic trend of Jersey sires for first calving interval (days) from the across-country genetic evaluation by sire country of performance and birth year.

Trend in sires performing in South Africa changed from negative to positive and back to negative, whereas a zero genetic trend was observed for sires with daughters in Kenya.

No genetic trends were estimated for age at first calving. Jersey sires EBVs were not estimable with any reasonable accuracy in the across-country analysis because genetic variance and heritability estimates were not significantly greater than zero (Tables 4.11 and 4.13).

4.4. DISCUSSION

The purpose of carrying out within-country and across-country genetic analyses was to estimate genetic parameters for production and reproduction traits and to calculate breeding values of individual animals for these traits (genetic evaluations). This was achieved for the Jersey and Holstein-Friesian cattle performing in Kenya, South Africa and Zimbabwe. Previously, across country genetic evaluations have been based on multi-trait models with records from different western countries being treated as separate but correlated traits (Sigurdsson *et al.,* 1996; Mark *et al.,* 2005). This would accommodate presence of genotype-by-environment interaction, manifested in less than unity genetic correlations between country pairs (Falconer, 1952; Robertson, 1959; Montaldo, 2001; Yamazaki *et al.,* 2014). However, the type and amount of data to accurately estimate these genetic correlations were not available in the present study. Approximate genetic correlations were derived instead, based on the method of Montaldo and Pelcastre-Cruz (2012). This approximation has been widely accepted as a realistic alternative (e.g Vargas and Gamboa, 2008; Montaldo *et al.,* 2009; Montaldo and Pelastre-Cruz, 2012). In the present study, these estimates ranged from 0.58 to 0.83. A report by Mulder and Bijma (2006) suggested that a genetic correlation as low as 0.40 to 0.60 may indicate the need to develop breeding programs for mutual selection and sharing of sires and dams from each environment/country. Based on this, we concluded that a common breeding programme would be sensible in the countries of study and we proceeded in pooling cow records across country for joint genetic analyses.

Genetic links

Extensive exportation of Holstein-Friesian semen by the United States and other western countries to sub-Saharan Africa has taken place based on superior milk production and aggressive sales efforts (Anon, 1989). Holstein-Friesian and Jersey sires have been widely used for genetic improvement in several countries in SSA with varying levels of success (Theron and Mostert, 2009). In Southern and Eastern Africa, previous studies by Theron and Hofmeyr (1992) showed that imported dairy cattle semen purchased for artificial insemination in the past consisted of 72% Holstein-Friesian, 13.6% Jersey, 11.5% Ayrshire and 2.8% Guernsey semen. These sires are used for either pure or cross breeding purposes. This is evident by the introduction of proven exotic sires and heifers for genetic improvement purposes in indigenous breeds including artificial insemination and embryo transfer, among others (Jorjani, 2005; InterBull, 2005; 2009). Genetic links among the studied countries and breeds were identified and quantified. These links were either direct based on sires with daughters in multiple countries or indirect based on ancestors sires. Although, common bulls were too low to calculate correlations for other country pairs and traits, it is recommended that quality data collation and recording is done to ensure increased genetic links of sires between the countries. South Africa had the highest numbers of data for Holstein-Friesian and Jersey sires performing within country compared to Kenya and Zimbabwe, which was a reflection of the cattle population sizes in these countries. We concluded that genetic links required in order to enable across-country parameter estimation and genetic evaluations were present among the three countries to attempt joint analyses.

Phenotypic and genetic trends

Phenotypic and genetic trends help farmers to assess management practices and selection response and compare alternative methods for genetic improvement (Javed *et al*., 2007; Norman *et al.,* 2009). Genetic trends in mean breeding values changed significantly for milk production and reproduction traits in sires performing across the three countries. Across-country genetic trends included some sires from countries with zero heritability in the within-country analysis. These countries would be the first to benefit from joint (across-country) evaluations as it would have been impossible to assess genetic trend based on national data only. The genetic trends in Kenya, South Africa and Zimbabwe fluctuated over the years. Changes affecting both trends could have been due to several factors including herd/farm management systems, climatic conditions, environment and genetic merit of sires used. Phenotypic trend in milk yield changed over the years which were evident in the genetic trends. Phenotypic trends are mainly affected by factors such as herd/farm management systems, climatic conditions and environment (Walsh *et al.,* 2011). Previous studies in South Africa showed that between 2001 and 2007 there was fluctuation in milk prices which led to an unexpected seasonal drop and decline in milk production and prices in the winter (MERC, 2007; 2008). The winter season in South Africa (June-August) is when milk production peaks and usually farmers receive higher milk prices. This continued until 2007 when severe milk shortages due to non-involvement of farmers in dairying led to milk price increase by 35% (MERC, 2007; Scholtz and Grobbler, 2009). Also, cost of milk production by dairy farmers in South Africa increased which led to decrease in milk yield and an adverse effect on milk yield trend (MERC, 2014). Lower and desirable trends in age at first calving for Holstein-Friesians within South Africa may have been due to adequate herd management systems where heifers got to production stage at a younger age which in turn, increased the productive life and status of the cows.

In Zimbabwe, milk recording stopped in year 2000 (Cuthbert Banga, personal communication) which explains the flat trends and sharp decline from 2001 to 2008. Trends started to increase from 2009 when dairy recording was taken over by research stations. Genetic trends in fertility traits in Zimbabwe (AFC) and South Africa (AFC and CI1) could depict the predominance of high performing sires with lower and negative EBVs due to the active participation of farmers in dairy production. The drastic change in Holstein-Friesian milk yield in the country is in agreement with previous reports by Ngongoni *et al*. (2006), Mostert *et al.* (2010) and Banga *et al*. (2014a). In general, flat trends were exhibited in phenotypic and genetic trends for 305-day milk yields in first and five lactations for both breeds in Kenya and Zimbabwe. This implies that there has been either no or slow genetic progress in place in these countries.

Changes in Kenya trend over the calving year period were due to few data recording at the time, environmental factors such as the onset of the El-Niño drought with low rainfall resulting to lack of food and water for the animals (Kirui *et al.,* 2015) and poor farm herd management systems (Mapiye *et al.,* 2006). Sire genetic trend in milk yield changed over the years within Kenya and is in agreement with previous findings (Ojango and Pollott, 2002; 2005, Ojango *et al*., 2010). Therefore, appropriate information in terms of EBVs and reliabilities of foreign sires used in countries in Africa should be put into consideration to ascertain how they perform in other countries for genetic improvement.

Desirable genetic trend for South Africa depicts an indication of better genetic improvement measures and breeding policies being in place in South Africa compared to the other two countries. This includes South Africa’s membership to INTERBULL in 1999 to enhance genetic evaluations procedures of exotic breeds to meet standards of other member countries (InterBull, 2009). Other factors that would have contributed to the desirable trend in age at first calving include; good breeding strategies, selection and use of proven sires with good reliability and breeding values for fitness traits, and good management systems and synchronisation of cows at the same time to oestrus for artificial insemination (Kahi *et al*., 2004; Jorjani, 2005). In Jerseys, over the years, milk yield changed differently in the two countries. Changes have been due to management systems and climatic conditions within the countries. In South Africa Jersey sires, similar genetic trend for 305-day milk yield was seen in previous studies by Mostert *et al.* (2006) using test-day records. Kenya genetic trend in CI1 was essential over the time considered indicating the lack of any deliberate effort to improve this trait.

The unfavourable phenotypic and genetic trend exhibited in some traits in the present study requires adequate data collation and recording for the future so as to make across-country evaluations meaningful. Our current study has shown a considerable decline in phenotypic and genetic trends over time within Kenya for all traits and for interval between first and second calving in Zimbabwe when compared to South Africa. This implies that there has been no adequate and consistent genetic improvement methods practiced within these countries. To enhance a desirable trend in sub-Saharan Africa, farmers will need to monitor their genetic progress to inform selection decisions thereby, advancing their herds in the direction that they intend. As payment is received for yield traits, farmers have customarily focused on selection (Hansen, 2013) and non-productive traits have been neglected. The increasing accuracy of estimated breeding values (EBVs) produced routinely in the past two to three decades in South Africa, have aided these selection decisions.

Genetic parameters and phenotypic performance

Heritability and repeatability estimates for the studied traits varied across country, trait and breed. The accuracy of these estimates improved in the across-country genetic analyses compared to within country estimates. Heritability estimates for milk production were comparable to those obtained previously for the South African Holstein population (Tesfa, 2002). First lactation milk yield was lower than previous reports of Makghalela *et al.* (2008). Heritabilities for CI1 and AFC in South African Holstein-Friesians were similar to previous studies by Makgahlela *et al*., 2007 despite the differences in data used. Ojango and Pollott (2001) reported higher heritability for milk yield (0.29) and Muasya *et al.,* 2014 reported moderate heritability of 0.17 (s.e= 0.29).

The low estimates may have been due to poor data quality compared to South Africa data. In addition, there were fewer animals in their later lactations than in first lactation. A previous study by Imbayarwo-Chikosi *et al*., 2001, reported lower estimates of 0.09 (s.e= 0.03) and higher repeatability of 0.17 (s.e= 0.03) in more than three lactations and 0.10 (s.e= 0.09) for first lactation. Heritability for age at first calving was lower in Zimbabwe (0.10 s.e= 0.04) than in South Africa (0.16 s.e= 0.03) and not different from zero in Kenya. The accuracy of this estimate improved in the across-country analysis (0.17 s.e= 0.02; P<0.01).

Heritability estimates for age at first calving and milk yield in all lactations were moderate and lower than those reported for Holstein-Friesians in South Africa (Makghalela *et al*., 2008, Rege, 1991). The moderate heritability for AFC and production traits within South Africa and Zimbabwe indicate that there is potential for improvement of these traits through selection. Heritability for CI1 was lower in Zimbabwe than South Africa and non-estimable in Kenya. Genetic correlations between milk yield and CI1 were favourable in across-country genetic analysis than within-country. This implies that it is possible to have indirect gain, if genetic selection for milk yield is done resulting in a shorter CI1 (Seno *et al*., 2010). The low heritability estimate for CI1 has been shown in previous studies on Holstein-Friesian cattle (Hoekstra *et al*., 1994; Veerkamp *et al*., 2001; Olori *et al.*, 2002; Wall *et al*., 2003). Generally, heritability for fertility traits improved in accuracy in across-country analysis. Heritabilities for all traits in the within Kenya analyses were not reliable as genetic variance estimates were not significantly different from zero. However, legitimate estimates were derived in joint (across-country) analyses including data from Kenya. Therefore, it would be necessary for Kenya to select sires from across-country genetic evaluations as within-country evaluations would not be reliable. This would also aid their cow daughters to attain their first calving at a shorter age and shorter days to second calving. Given the limited within-country data, Kenya will benefit the most from the joint evaluations for both production and fitness traits.

Accuracy of heritability for 305-day milk yield in five lactations for Jersey cattle improved in across-country evaluation as manifested by smaller standard errors. Similar estimates were reported by Mostert *et al*. (2006) for Jersey cows performing within South Africa (0.18 se= 0.01). Missanjo *et al.* (2010) reported higher heritability for 305-day milk yield (0.30 s.e= 0.10) for Jersey cows in Zimbabwe. Another study by Musani and Mayer (1997) reported moderate heritability estimates for milk yield and repeatability of 0.20 and 0.24, respectively in Kenya. These differences in heritability estimates may have been due to differences in the type of statistical model used for genetic estimation, and the inability to fully account for the growth environment of the cows in their analyses.

Cattle in South Africa and Zimbabwe had milk yield and age at calving more similar to previous studies (Theron and Mostert, 2009; Tesfa *et al.,* 2004) than Kenya. This may have been attributed to an efficient management system in place. Compared to our estimates, Sattar *et al*. (2005) reported higher age at first calving of 33.10 SD= 0.37 for Jersey cows raised in sub-tropical conditions of Punjab, India. Higher age at first calving and milk yield has been reported for Holstein-Friesians in Kenya (Rege, 1991; Ojango and Pollott, 2001; Muasya *et al*., 2014), while Menjo *et al*. (2009) reported lower heritability of 0.15 (s.e= 0.06) with cows calving at an average of 1,058 days. The mean AFC and CI1 for joint evaluation were 30 months and 464 days respectively. Although, mean of AFC and CI1 in South African and Kenyan Holstein were higher than in previous reports (Makgahlela *et al*., 2008; Hultgren and Svensson, 2010; Faraji-Arough *et al.*, 2011), genetic parameter estimates were lower. Again, these results agree with estimates of Iranian Holstein (Farhangfar and Younesi, 2007; Chookani *et al*., 2010). The differences in AFC estimates may be due to poor heifer management systems, feeding regimen, herd health, genetic variation, and varying reactions of the same breed to different environmental conditions. Generally, fitness (fertility) traits are low in heritability compared to production. Experiences from other countries have shown selection on production only leads to a decline in fitness traits (LeBlanc, 2010; Chebo and Alemayehu, 2012). The estimation of heritabilities and EBVs provide an opportunity to include these traits in selecting bulls to ensure sustainability.

Previous studies have shown that dairy cattle in Africa tend to move from herd to herd (e.g. De Leeuw *et al.,* 1998). This is an aspect that has not been exploited or considered in African dairy cattle genetic evaluations. It is generally known that the effect of dairy cattle movement and changing management systems has an impact on the general performance of these cows in terms of productivity (Ojango and Pollott, 2002). In sub-Saharan Africa, there is a high movement of animals especially heifers from one herd to another before they get to their productive life. Cow movements across herd are majorly due to either being given out as dowry in marriages or within the “pass on a cow” programme like the Gi’rinka practiced in Rwanda, Kenya, Malawi, Tanzania, among others (Gitahi, 2003). Previous studies have shown that growth environments affect the performance of heifers in their later life (Ojango and Pollott, 2002). Cow growth environment should be taken into consideration for now and for the future in within and across-country genetic evaluations for Holstein-Friesians and other dairy breeds currently used in sub-Saharan Africa. In this chapter, joint genetic evaluations increased the value of the genetic parameter estimates and accuracy as reflected in low standard errors associated with the estimates. This would generally help to increase the accuracy of selection especially where there are insufficient data available in individual countries for a robust analysis. Therefore, the present study has demonstrated the feasibility of a joint genetic evaluation for both breeds and the possible benefits in terms of increased accuracy of selection and availability of more sires to select from; especially for Kenya and Zimbabwe.

Sire reliability

Sire EBV reliabilities increased in the across-country genetic evaluations compared to within-country, when EBVs were estimable in the latter. In some cases, within-country EBVs could not be derived because genetic variance and genetic parameter estimates were not different from zero. Across-country genetic evaluations would then be the only method that the genetic merits of sires from these countries could be reliably estimated.

4.5. CONCLUSION

The feasibility of an across-country genetic evaluation using pooled data was demonstrated in this chapter. The study carried out on Holstein-Friesians and Jersey breeds performing in Kenya, South Africa and Zimbabwe revealed realistic genetic parameter estimates from across-country analyses that were more accurate than within-country estimates. Across-country genetic evaluations could provide robust and optimum genetic estimates that can be used to enhance genetic progress and optimise future breeding strategies in sub-Saharan Africa. Genetic evaluations across countries can be enhanced through adequate capacity building in terms of training personnel in the field of quantitative genetics and data collation so as to enhance availability of adequate data recording systems. As more data accumulates, the best approach would be to adopt similar models as used by the InterBull Centre with records from different countries treated as separate but correlated traits to account for genotype by environment interaction properly. Quantifying the amount of genetic gain arising from selecting Holstein-Friesian and

Jersey sires within and across country is another aspect that needs to be addressed on breeding programme design and is examined in the next Chapter.

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CHAPTER 5

5.0. Prediction of genetic gains from within and across country genetic selection

5.1. INTRODUCTION

The annual rates of genetic improvement in key traits of economic importance are used as measures of success of breeding programmes. In recent times, very significant progress has been achieved in the improvement of milk, fat and protein yields in dairy cattle. This has been due to successful breeding programmes in a growing number of countries, domestic and global availability of genetically superior sires for artificial insemination and the introduction of embryo technologies (Kugonza *et al.,* 2013). However, evaluation of whether this progress manifests in increased profits has been less well documented, especially in developing countries in Africa. This is primarily because of variations in breed, environmental influences and management systems which often mask the genetic response (Roibas and Alvarez, 2010). Initially, genetic selection of superior cattle was probably limited to docility and manageability. In the last six decades, breeding programmes have focused on the genetic improvement of animal production traits such as milk yield, growth rate and number of eggs (Hazel, 1943; Oltenacu and Broom, 2010). The primary goal in dairy cattle breeding is to improve the profitability of milk production; therefore, a sound dairy breeding objective should include all desirable traits that are economically relevant to dairy production. Increasingly, breeding objectives include health and fertility traits (Pryce *et al*., 1998; Olori *et al*., 2003).

In sub-Saharan Africa, only South Africa has a sustainable national animal identification and performance recording scheme, as well as routine genetic evaluation programmes (Ramatsoma *et al.,* 2015). Significant changes have occurred in recent years which have gradually led to more balanced breeding objectives. These comprise of a wider range of economically relevant traits especially in the Holstein-Friesian breed in developed countries (VanRaden, 2004; Wesseldijk, 2004; Miglior *et al.,* 2005). Recently, there has been the need to apply these processes to developing more comprehensive dairy cattle breeding objectives for foreign breeds such as the Holstein in Africa (Banga, 2009, Banga *et al.,* 2014b) and Jersey (Banga, 2009). In Kenya, breeding goals for Sahiwal (Ilatsia *et al.,* 2011) and Kenyan dual purpose goats (Bett *et al.,* 2007) for improved productivity have been examined but there is limited information on the situation of foreign breeds in Zimbabwe (Mpofu *et al.,* 1993).

The inadequacies of breeding programmes are a serious challenge to livestock production in developing countries. Generally, farmers do not have access to high quality, well adapted germplasm, and there are no systems for supporting sound breeding decisions for appropriate genetic improvement programmes. Genetic selection based on robust genetic evaluation is an important pre-requisite to any breeding programme. Few developing countries, however, perform routine genetic evaluations (Chebo and Alemayehu, 2012) and there is limited availability of data and recording systems among the countries (Ojango *et al.,* 2017). In Chapter 4, it was shown that this may not even be possible in some countries nationally due to data limitations.

Joint genetic evaluations and across-country selection of the best animals may have several benefits, including sharing of resources and increased genetic gains. Usually genetic progress in the dairy system is through the four pathways: bulls to breed bulls (bb), bulls to breed cows (bc), cows to breed bulls (cb) and cows to breed cows (cc). Schmidt and Van Vleck (1974) indicated that the proportions of genetic gains from the four pathways are: cc= 2%, bc= 27%, cb= 32% and bb= 39%, implying that most of the genetic improvement (about 66% (bb + bc)) results from the selection of bulls. The hypothesis is that individual countries in the countries studied could benefit more from selecting sires across different countries than using only their own national resources or sires. Given that individual farmers in developing countries are unlikely to intentionally select on the cow pathway to improve genetic gain, the objective of this Chapter is to therefore assess and compare genetic progress from the sire pathway that may be achieved from joint and across-country genetic evaluation and selection. Therefore, the relative rate of genetic progress reported in this Chapter represents about 66% of the total possible genetic progress as cow information has not been incorporated.

5.2. MATERIALS AND METHODS

Data were outcomes from within-country and across-country genetic analyses described in Chapter 4 including genetic variance estimates and sire EBVs and reliabilities. Genetic gains per generation (R) were predicted for each country, trait and breed based on these outcomes using the Breeders' equation (Falconer and Mackay, 1996):

$$\boldsymbol{R = i.\rho.\sigma g} \qquad [7]$$

Where;

$\boldsymbol{R}$: Predicted genetic gain per generation (Response to selection).

$\boldsymbol{i}$: Selection intensity.

$\boldsymbol{\rho}$: Accuracy of selection (square root of reliability of EBVs).

$\boldsymbol{\sigma g}$: Square root of trait genetic variance estimate.

In this study, values of i and ρ were derived for sires only. As explained in section 5.1, sire selection is expected to account for around 66% of the overall genetic gain. Different selection intensities were tested based on selection of the top 5, 10, 25, 50, 75 and 100 sires within- and across-country. In a separate analysis, only sires with a minimum reliability of 30% were considered as selection candidates. In each case, selection intensities were calculated after accounting for the number of selection candidates and accounting for the finite population size. Relative selection response within-country was compared to the relative selection response across-country.

5.3. RESULTS

5.3.1. Selection intensity based on within- and across-country genetic selection

5.3.1.1. Holstein-Friesian breed

Table 5.1 shows selection intensities corresponding to selection of the top 5, 10, 25, 50, 75 and 100 Holstein-Friesian sires within country and across the three countries.

Table 5.1: Intensity of selection of top 5 to 100 Holstein-Friesian sires selected within- and across-country.

		Top 5 sires		Top 10 sires		Top 25 sires		Top 50 sires		Top 75 sires		Top 100 sires	
	No. of sires available for selection	Proportion Selected	Intensity of selection	Proportion selected	Intensity of selection	Proportion selected	Intensity of selection	Proportion selected	Intensity of selection	Proportion selected	Intensity of selection	Proportion selected	Intensity of selection
KEN	103	4.85%	2.03	9.71%	1.74	24.27%	1.28	48.54%	0.82	72.82%	0.45	97.09%	0.07
SA	505	0.99%	2.63	1.98%	2.40	4.95%	2.06	9.90%	1.76	14.85%	1.56	19.80%	1.40
ZW	236	2.12%	2.35	4.24%	2.10	10.59%	1.72	21.19%	1.36	31.78%	1.12	42.37%	0.92
Across-country	844	0.59%	2.80	1.18%	2.59	2.96%	2.27	5.92%	1.99	8.89%	1.81	11.85%	1.67

Footnotes: KEN (Kenya); SA (South Africa); ZW (Zimbabwe).

As expected, selection intensity increased as proportion of selected sires decreased. Also, selection intensity was always greater when selecting from the joint pool (across country).

5.3.1.2. Jersey breed

Table 5.2 shows selection intensities corresponding to selection of the top 5, 10, 25, 50, 75 and 100 Jersey sires within country and across the two countries.

Table 5: Intensity of selection of top 5 to 100 Jersey sires selected within- and across-country.

		Top 5 sires		Top 10 sires		Top 25 sires		Top 50 sires		Top 75 sires		Top 100 sires	
	No. of sires available for selection	Proportion selected	Intensity of selection	Proportion selected	Intensity of selection	Proportion selected	Intensity of selection	Proportion selected	Intensity of selection	Proportion selected	Intensity of selection	Proportion selected	Intensity of selection
KEN	35	14.29%	1.53	28.57%	1.16	71.43%	0.46	-	-	-	-	-	-
SA	771	0.65%	2.77	1.30%	2.56	3.24%	2.23	6.49%	1.95	9.73%	1.77	12.97%	1.63
Across-country	806	0.62%	2.79	1.24%	2.57	3.10%	2.25	6.20%	1.97	9.31%	1.79	12.41%	1.65

Footnotes: KEN (Kenya); SA (South Africa).

Similarly, selection intensity increased as proportion of selected Jersey sires decreased. Also, selection intensity was always greater when selecting from the joint pool (across-country). The scenarios of selecting top 50-100 sires within Kenya were not realistic since the number of locally available sires was only 35.

5.3.2. Predicted genetic gain per generation from within- and across-country selection

5.3.2.1. Holstein-Friesian breed

Predicted response to selection of top sires within- and across-country are shown in Tables 5.3 and 5.4 for milk production traits and in Tables 5.5 and 5.6 for reproduction traits. These results pertain to selection scenarios in Table 5.1. Appendix 5 included the same results pertaining to selection candidates with minimum sire EBV reliability of 0.30. Sire pathways account for around 66% of overall genetic gain.

Table 5.3: Predicted genetic gain (PGG) per generation from sire pathways only for 305-day milk yield (litres) in first lactation from within- and across-country genetic selection (Holstein-Friesians).

			Top 5 sires		Top 10 sires		Top 25 sires		Top 50 sires		Top 75 sires		Top 100 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
South Africa	398.77	0.61	640.14	80%	584.87	80%	501.10	78%	428.12	76%	379.47	74%	340.55	72%
Zimbabwe	168.82	0.38	151.32	19%	134.72	18%	110.34	17%	87.25	15%	71.85	14%	59.02	12%
Across-country	450.79	0.63	796.36	100%	735.56	100%	644.68	100%	565.16	100%	514.04	100%	474.28	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

Regardless of selection intensity, selection based on across-country genetic evaluation resulted in highest response for 305-day milk yield in first lactation in all countries. Zimbabwe would only achieve 12-19% of genetic response from within country genetic evaluations compared to across country. This translates to a benefit of 81-88% and is higher than South Africa (20-28%).

A 100% benefit in Kenya was achievable from across-country genetic evaluation and selection because genetic estimates (heritability and genetic variance) were not significantly different from zero for in the within-country analysis; hence, no genetic gain may be expected in Kenya based on within-country genetic evaluation.

Table 5.4 presents predicted response to selection for 305-day milk yield in five lactations when Holstein-Friesian sires were selected within- and across-country.

Table 5.4: Predicted genetic gain (PGG) per generation from sire pathways only for 305-day milk yield (litres) in five lactations from within- and across-country genetic selection (Holstein-Friesians).

			Top 5 sires		Top 10 sires		Top 25 sires		Top 50 sires		Top 75 sires		Top 100 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
South Africa	436.21	0.67	774.38	98%	707.53	97%	606.18	95%	517.90	93%	459.05	90%	411.97	88%
Zimbabwe	255.03	0.59	353.86	45%	315.03	43%	258.03	41%	204.02	37%	168.02	33%	138.01	29%
Across-country	423.07	0.66	786.93	100%	726.85	100%	637.04	100%	558.47	100%	507.95	100%	468.66	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

Zimbabwe benefited by 55-71% from across-country selection for increased 305-day milk yield in five lactations and 2-12% in South Africa. A 100% benefit in Kenya was achievable from across-country genetic evaluations because genetic estimates (heritability and genetic variance) were not significantly different from zero for 305-day milk yield in five lactations; therefore, no genetic gain could be expected in Kenya from within country genetic evaluation.

Within country, there were no genetic gains for reproduction traits and interval between first and second calving for Kenya and Zimbabwe, respectively (Tables 5.5 and 5.6). Therefore, these countries achieved a 100% benefit from across-country evaluation and selection.

For age at first calving, Zimbabwe benefited 27-41% from across-country evaluations (Table 5.5). Table 5.6 shows predicted genetic gain for interval between first and second calving for within and across-country Holstein-Friesian. In general, although Kenya and Zimbabwe would achieve the greater benefit from across-country selection using these hypothetical scenarios, South Africa would stand to benefit too compared to selecting within-country albeit to a lower extent than the other two countries.

Table 5.5: Predicted genetic gain (PGG) per generation from sire pathways only for age at first calving (days) from within- and across-country genetic selection (Holstein-Friesians).

			Top 5 sires		Top 10 sires		Top 25 sires		Top 50 sires		Top 75 sires		Top 100 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
South Africa	31.76	0.70	58.20	84%	53.17	86%	45.56	81%	38.92	79%	34.50	77%	30.96	75%
Zimbabwe	26.93	0.45	28.46	41%	25.45	41%	20.84	37%	16.48	34%	13.57	30%	11.15	27%
Across-country	37.77	0.65	69.11	100%	61.87	100%	55.95	100%	49.05	100%	44.61	100%	41.16	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

Table 5.6: Predicted genetic gain (PGG) per generation from sire pathways only for interval between first and second calving (days) from within- and across-country genetic selection (Holstein-Friesians).

			Top 5 sires		Top 10 sires		Top 25 sires		Top 50 sires		Top 75 sires		Top 100 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
South Africa	13.19	0.37	12.70	35%	11.60	45%	9.94	34%	8.49	36%	7.53	32%	6.76	31%
Zimbabwe	0.00	0.00	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
Across-country	23.06	0.57	36.58	100%	33.79	100%	29.61	100%	25.96	100%	23.61	100%	21.79	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

5.3.2.2. Jersey

Predicted genetic gains for production traits from selecting top sires within and across-country are shown in Tables 5.7 and 5.8, and for interval between first and second calving shown in Tables 5.9. These results pertain to selection schemes based on Jersey sires shown in Table 5.2. In Appendix 5, similar results pertain to selection candidates with minimum sire EBV reliability of 0.30. Again, sire pathways account for around 66% of overall genetic gain.

Unfortunately, genetic parameters for age at first calving were not significantly different from zero in within- as well as across-country analyses in this study. Therefore, no genetic gains could be predicted for this trait for the Jersey breed.

Table 5.7: Predicted genetic gain (PGG) per generation from sire pathways only for 305-day milk yield (litres) in five lactations from within- and across-country genetic selection (Jersey).

			Top 5 sires		Top 10 sires		Top 25 sires		Top 50 sires		Top 75 sires		Top 100 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
South Africa	399.66	0.76	838.73	97%	775.14	98%	675.22	97%	590.44	97%	535.94	97%	493.55	97%
Across-country	409.26	0.75	861.44	100%	794.09	100%	695.21	100%	608.70	100%	553.08	100%	509.82	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

Kenya benefited the most (100%) from across-country selection for increased 305-day milk yield in first and all five lactations than South Africa (2-3% and 15%, respectively). Although, genetic and management resources within Kenya may be inadequate, they have the opportunity to optimise milk yield from improvement strategies of other countries (like South Africa) and from a joint genetic evaluation. Table 5.8 shows response to selection for 305-day milk yield in first lactation for Jersey sires performing within country and in the 2 countries.

Table 5.8: Predicted genetic gain (PGG) per generation from sire pathways only for 305-day milk yield (litres) in first lactation from within- and across-country genetic selection (Jersey).

			Top 5 sires		Top 10 sires		Top 25 sires		Top 50 sires		Top 75 sires		Top 100 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
South Africa	373.25	0.63	651.85	85%	602.44	85%	524.78	85%	458.89	85%	416.53	85%	383.58	85%
Across-country	409.91	0.67	766.38	100%	706.46	100%	618.49	100%	541.52	100%	492.05	100%	453.56	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

Table 5.9: Predicted genetic gain (PGG) per generation from sire pathways only for interval between first and second calving (days) from within- and across-country selection (Jersey).

			Top 5 sires		Top 10 sires		Top 25 sires		Top 50 sires		Top 75 sires		Top 100 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
South Africa	15.46	0.38	16.24	69%	15.01	70%	13.07	69%	11.43	69%	10.38	69%	9.56	69%
Across-country	17.86	0.47	23.38	100%	21.55	100%	18.87	100%	16.52	100%	15.01	100%	13.84	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

For interval between first and second calving, Kenya again benefited the most (100%) than South Africa (30-31%).

Results in Appendix 5 pertain to benefits that could be accrued when a minimum of 30% is implemented on sire reliability. This is to ensure a more robust and efficient breeding programmes that would be sustainable in SSA. To optimise an effective and efficient genetic improvement programme within and across the three countries, selection of sires with minimum reliability of 30% led to sires with higher reliabilities being selected. Details are shown in Supplementary Tables 1 to 7 in Appendix 5. Average reliability was higher in evaluations across- than within-country. For Holstein-Friesians, reliability for production and early reproduction traits in Kenya and CI1 in Zimbabwe were not estimable since genetic estimates were not significantly different from zero. For production traits in South Africa sire reliabilities ranged from 47-50%, in Zimbabwe 38-45%, and across-countries, they averaged 51%. For reproduction traits, sire reliabilities were higher in South Africa (36-52%), than in Zimbabwe (0-41%), and even higher across the two countries; 43 and 66% (Supplementary Table 1). For Jersey sires, average reliability for production traits within South Africa and in joint evaluation remained the same (58-61%). For interval between first and second calving, reliability ranged between 43 and 44%.

In general, results in Appendix 5 are consistent with results presented here without implementing any limits to sire EBV reliability.

5.4. DISCUSSION

The aim of this study was to predict response to selection and genetic gains in Holstein-Friesian and Jersey cattle population in Kenya, Zimbabwe and South Africa, when selection of sires was based on within- and across-country genetic evaluations. As indicated earlier, since only the sire pathways have been considered in these computations, the rate of genetic gain reported represents approximately about 66% (Schmidt and Van Vleck, 1974) of possible genetic progress. Genetic parameters obtained in previous Chapters were used to deterministically predict annual genetic gain for each country and trait separately. Different selection intensity scenarios were tested. In all scenarios, the options to select from across country genetic evaluation led to higher annual genetic gains for the individual countries.

Kenya and Zimbabwe would stand to benefit the most from across country evaluations. South Africa, with the largest cattle population amongst the three countries, would also benefit but to a lower extent. However, this enhances trade opportunities for South Africa to export their sires to countries in Africa with poor genetic improvement in place. Response to selection and genetic progress has been carried out in previous studies for a few dairy breeds (e.g. Holsteins) performing in Africa (Mpofu *et al.,* 1993; Banga *et al.,* 2014b; Missanjo *et al.,* 2010) and within and across breeds in developed countries (Nilforooshan, 2011; Lidauer *et al.,* 2015). The proportions of genetic predictions of the former for production and functional traits ranged from 4 to 91.1% compared to our within-country predictions (0 to 97%). However, there is a lack of information for these breeds performing across multiple countries in sub-Saharan Africa.

An important method of evaluating the effectiveness of a dairy breeding programme is to measure response to selection (Mandizha *et al.,* 2000). Across-country bull selection could accelerate genetic progress, especially when countries have similar breeding objectives (Banos & Smith, 1991). International (across-country) genetic evaluations provide a large multinational reference population, which allows higher genetic response, as larger numbers of bulls are being tested. Breeding goals in the past have focused mainly on production traits (Pryce *et al.,* 2007), at the expense of fertility traits and other economic traits of interest. However, recent research has gradually led to more balanced and efficient breeding objectives comprising a wider range of economically important traits (Philipsson *et al.,* 1994; VanRaden, 2004; Wesseldijk, 2004; Miglior *et al.,* 2005). Recently, there has been a pressing need to apply these advances in knowledge to developing more comprehensive dairy cattle breeding objectives in Kenya (Kahi *et al.,* 2004; Njarui *et al.,* 2014), South Africa (Banga, 2009; Banga *et al.,* 2014b) and Zimbabwe (Mpofu *et al.,* 1993; 2002).

Across-country genetic selection has not been carried out in Africa (Banga, 2009). Genetic selection and progress in cattle has been slow over the years and there is increased need to augment and improve current genetic evaluation procedures in Africa so as to optimise milk yield and milk products. Therefore, cattle farmers need to intensify efforts in developing an efficient milking herd for the future in SSA. The feasibility of this approach will be for small-holder farmers to share information among farms and make use of proven sires and dams to optimise milk yield, and for the dairy sector and government to provide support to small-holder farmers. A major principle of animal breeding is to select top pure-bred animals to become parents that could improve the genetic level in the next generation (Toghiani, 2012).

A multi-trait genetic selection programme that enhances animal health, fertility, and other desirable welfare traits should be included in breeding objectives (Oltenacu and Broom, 2010). The primary aim of an efficient dairy production strategy in Africa should aim at striking a balance between animal welfare and production traits that are well adaptable to the environment and small-holder dairy systems. Previous studies by Van der Westhuizen and Van der Westhuizen (2009) predicted that the use of a selection index which includes multiple traits of interest should be considered in order to increase selection index efficiency. However, it should be known that every country needs its own genetic selection programme. Missanjo *et al.* (2010) postulated that every country should have its own genetic improvement programme even though breeding goals may be similar. This is because the success of a genetic improvement programme relies on the use of adequate breeds and management systems. Genetic parameter estimates are important tools for improving the future of breeds (Panteliæ *et al.,* 2008). Therefore, in order to achieve optimum breeding goals, genetic information in terms of heritabilities, genetic variances and reliabilities must be known from the past in order to improve the future (CDN, 2010).

Genetic selections in sub-Saharan Africa

Generally, the EBVs of foreign and indigenous sires in Africa, when available, have low reliability. This may be due to lack of suitable data or poor data structure. From our study, predicted genetic gains were not estimable from within- and joint genetic evaluations for AFC in the Jersey breed. This could be attributed to poor data structure in Kenya and the inability to de-compose the genetic variance for Jerseys performing in South Africa from the across-country analyses in Chapter 4. Despite the importation of genetic material, some countries are not able to embark on an adequate national selection programme. Importation of semen and embryos has been stimulated by the need to enhance the current dairy populations in Africa with varying degrees of success. In Kenya, the low success rate of current national selection programmes (Ojango and Pollott, 2002) is due to the use of low-merit genetic materials involving progeny testing of bull even though they are foreign sires (Okeno *et al.,* 2010). In other instances, sires with very low estimated breeding values are used for breeding. Previous studies by Okeno *et al*. (2010) have shown that to achieve an adequate genetic merit in dairy production, genetic correlations of imported semen must be greater than 0.58 for Kenya sires currently used for national evaluations. A substantial amount of progress was made but rather became slow over time. This can be attributed to poor breeding infrastructure and lack of well-defined national breeding goals (Mpofu, 2002). The poor reproductive performance for Holstein-Friesian breed as shown with low heritability and reliability for CI1 in Zimbabwe, AFC and CI1 in Kenya and AFC for South Africa Jersey breed in the present thesis may have been due to effects on poor genetic strategies and management system. However, benefits were derived with across-country genetic evaluations.

Response to selection and genetic gains

Across-country genetic evaluations would benefit individual countries to a different extent. Countries in need of immediate advancement in future dairy strategies could rely on importations from other African countries with more advanced breeding programmes such as South Africa. This means that when national genetic evaluations within countries are not reliable, there are opportunities for such countries to benefit from international (across-country) evaluations and select bulls for their traits of interest. Also, South Africa with the lowest potential benefit from across country evaluations could serve as a “hub” where by genetic materials are being marketed and exchanged internationally to other countries in need of genetic improvement and with similar breeding goals. For the last several decades, genetic improvement in SSA has clearly shown that reliance on importations of germplasms has created a sense of “dependency” and hindered development of strong national breeding systems and institutions that support them. Therefore, SSA countries in need of advances in their breeding programmes should firstly; develop a strong, reliable and sustainable national dairy programme and secondly; build human capacity and institutional supports to avoid total dependency on others whilst importing genetics from other Africa/Western countries with advanced genetic programmes in place.

In general, across-country genetic evaluations can benefit breeding programmes in SSA in terms of increased response to selection. It is fundamental that countries work together by making data available and accessible for joint genetic analyses. There is a great potential to improve desirable traits by using sire information from different countries compared to relying on limited within country information. Also, countries which have better rates of genetic improvement may continually maintain or improve what they have in place so as to maximise genetic gain and progress.

Joint evaluations could help to inform individual countries on their farm management practices, breeding programmes. It will also aid in the inclusion of top performing common sires within country in order to inform future breeding strategies leading to genetic gain. Results based on data from Kenya, South Africa and Zimbabwe demonstrate that putting together animal production and reproduction records in a joint genetic evaluation is feasible and will result in higher genetic gains than any within-country evaluation. From our study, predicted genetic gain per generation was treated as uniform (similar sire accuracies). This was because sires were born across random years. As selection in SSA is mainly based on selection of bulls, response per generation could take five years or more. The opportunity for genomic selection of selected bulls could help optimise dairy production and enhance adequate genetic improvement for future breeding strategies.

5.5. CONCLUSION

Individual countries benefitted from joint evaluations for both production and fertility traits. The present study can be seen as a pilot study of three countries, two breeds and four traits. The concept can be easily expanded to cover more countries, breeds and traits across Africa. To further enhance the prospects of across-country genetic evaluation, it is proposed that countries harmonise methods for collection of data to ensure similar formats and trait definition applied. This will increase the accuracy of records and hence, genetic parameters from joint genetic evaluations. It is also proposed that the key to genotyping of sires used across several countries will be useful and pave the way for genomic selection across various countries in SSA.

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CHAPTER 6

GENERAL DISCUSSION

This thesis set out to assess (i) the current status, needs and opportunities of the dairy sector in sub-Saharan Africa and (ii) the possibility of developing international genetic evaluations of the foreign dairy breeds used in dairy production in several countries in sub-Saharan Africa.

The first technical part (Chapter 3) highlighted the need for systematic animal recording and related infrastructure to underpin national and international genetic evaluations of the dairy breeds currently used for dairying in Africa. There were significant differences in the challenges facing dairy production across the 15 countries and regions identified in the survey. The challenges identified by respondents which ranged from farm management problems, poor cow performance and pedigree data recording, inadequate feed resources, and insufficient market organisation for milk and milk products to limited genetic improvement methods have been previously addressed by Brokken and Seyoum (1990); Bebe *et al.* (2000); Kamuanga *et al.* (2001); Steinfield *et al.* (2006) and Kefena *et al.* (2011). The respondents identified the need for collaboration of multiple countries through information sharing and pooling current or future data so as to determine appropriate strategies for improving milk production across the different countries and regions in sub-Saharan Africa. Although challenges and needs facing dairy production in SSA were different across the countries and regions, the opportunities for genetic improvement of the dairy sector to contribute were similar.

The second part (Chapter 4) highlighted the potential and feasibility of carrying out joint (across-country) genetic data analyses of dairy cattle in sub-Saharan Africa. Genetic parameter estimates including trait heritability and correlations between traits from across-country genetic analyses for Holstein-Friesian and Jersey breeds were more accurate than within-country estimates having smaller standard errors. The ability to include herd of birth and herd of calving in the genetic evaluation models helped to account for the impact of environmental influences on the cows in the data. This helped in improving the accuracy of defining the contemporary group in the animal model used in our study compared to those reported by Ojango and Pollott (2001); Makgahlela *et al*. (2007); Ramatsoma *et al.* (2015) and Muasya *et al.* (2014). There are several dairy breeds currently used for milk production in Africa including Holstein-Friesian, Jersey, Guernsey, Brown-Swiss and Fleckvieh. Dual purpose breeds such as the Sahiwal are also used. Various factors affect milk production. These include genetic and environmental factors. The environmental factors are in the form of management systems and the physical environment in the different geographical locations. Evaluation of genetic factors in Africa is limited due to lack of adequate data. Joint (across-country) genetic evaluation is proposed in the present thesis as a possible novel approach that could enhance genetic gains by making more robust genetic evaluation system viable due to more data being available and hence promote the appropriate use of the best genetics available in the different countries. However, to achieve this, there would be a need for consistent and systematic animal performance recording in the individual countries and an agreement to share data between countries.

In an attempt to assess the feasibility of carrying out a joint genetic evaluation in dairy cattle currently used for milk production across different countries in sub-Saharan Africa, the present study used cow performance data from Kenya, South Africa and Zimbabwe pertaining to the Holstein-Friesian and Jersey breeds. Ideally, the joint genetic analyses of individual traits from the different country-pairs should have been based on a multi-trait model with the observations in each of the countries treated as separate traits. However, the limited data structure has not permitted this. Hence the joint analysis involved pooling data together and assuming that animal traits were genetically the same in the three countries.

Across-country genetic evaluations were possible even for those countries with limited data. Despite the fact that genetic variance and parameter estimates were low and statistically not different from zero for some traits in Kenya and Zimbabwe, these countries can be included and would benefit the most from joint genetic evaluations. This would aid in terms of informing their current state of genetic improvement and also finding ways of improving it. As mentioned above, results showed that in general, genetic parameter estimates from joint evaluations improved and they were more accurate compared to individual within-country genetic analyses.

The third technical part (Chapter 5) of this thesis highlighted predicted genetic gains for both breeds where sire selection was based on within- and across-country genetic evaluation. Predicted response to selection (genetic gain) showed how much more benefit the three countries could make if they selected the best 5 to 100 sires from joint (across-country) evaluations candidates compared to selecting within-country. Benefits were seen in all cases for both milk production and reproduction traits. Kenya and Zimbabwe would benefit the most while the lowest benefits accrue to South Africa. This demonstrates that by working together, countries would achieve higher genetic improvement than by working individually. This should also encourage the practice of systematic data recording and utilisation. Thus, across-country breeding programmes will have the tools to address the antagonism between production and functional traits in terms of more data.

This Chapter will now further discuss results from the present thesis, along with the current situations regarding data recording, international collaborations, across-country genetic evaluations in the African dairy sector, followed by recommendations and future work. The knowledge and implementation of sustainable breeding schemes are essential for the improvement of milk yield in sub-Saharan Africa. The results from the joint evaluations indicate possible genetic response for both production and functional traits which are essential for putting a sustainable breeding program together. A factor which this thesis has not addressed in terms of sustainable breeding program is the adaptability of different genotypes to varying environmental conditions. This would help farmers in the application and adaptation of specific genotypes based on their needs and prevailing circumstances to improve milk yield. A very recent study by Muluye *et al*. (2017) suggested the adequate matching of certain genotypes to the right production system (urban, peri-urban and rural production system). That is to say, dairy cattle with high genetic potential of 75% should be raised in urban areas, medium genetic potential of 50-62.5% in peri-urban areas and lower genetic potential of 25-50% to rural areas. Adapting the genotypes with the appropriate management practices such as feeding practices, health care and housing and regularly supplying dairy inputs can improve dairy productivity. For instance, farmers may intend to upgrade their indigenous breeds with higher exotic grades (Holstein, Friesian and their crosses) to enhance milk production and reproduction capacity as the overall productivity of the indigenous breeds in terms of such traits may be limited (Bebe *et al.,* 2000). In general, the continuous use of cross-breds of European and indigenous breeds by small-holder dairy farmers has proven to increase household incomes (Udoh, 2011, Marshall *et al.,* 2016) but with European pure breeds to a lesser extent. Therefore, the investigation and understanding of the current dairy farming systems and breeding methods could help to improve production performance per cow, as well as income and standard of living thereby increasing availability of milk in sub-Saharan Africa. Also future dairy breeding may also involve breeding for disease resistance thereby optimising the overall health status of the dairy cattle herds in sub-Saharan Africa.

In the major dairy breeding countries, there has been intensive selection for milk yield over the years (Dillon *et al.,* 2006; Walsh *et al.,* 2011). This has led to unfavourable genetic correlation between milk yield and fertility trait resulting in a down-ward trend in dairy cows (Pryce *et al.,* 2014, Sun *et al.,* 2009). Also, the unilateral selection for increased milk yield led to a reduction in health and fertility due to these antagonistic genetic correlations. Generally, poor fertility traits affect economic efficiencies in dairy cattle (Haile-Mariam *et al.,* 2003a, Mostert *et al.,* 2010). This may be even more detrimental in sub-Saharan Africa due to environmental effects and variations in farm management systems. In sub-Saharan countries, performance recording is often limited (Wasike *et al.,* 2012, Muasya *et al*., 2014). Genetic selection has not been very systematic. Where this was carried out, the trait of preference was milk yield (Chagunda *et al.,* 2004). Sire ranking by genetic merit is usually not carried out. Poor cow data and pedigree recording has limited the adequate genetic evaluations of dairy cattle in SSA. While some country's national evaluation may be efficient, some other countries have either none or a lack of within-country genetic evaluations in place. In order to tackle these inconsistences, the African dairy genetic gain (ADGG) program was set up (Okeyo, 2016). ADGG aims in developing and testing a multi-country genetic gains platform that utilises on-farm performance information and basic genomic data to identify and provide superior cross-bred bulls for artificial insemination (AI) delivery and planned natural mating to smallholder farmers in Africa. To achieve this, the ADGG is establishing performance data recording and sampling systems in Tanzania and Ethiopia using digital means such as mobile phones and tablets (https://news.ilri.org/2015/12/23/adgg/). Information and material for developing systems to select bulls and cows of superior genetic merit for artificial insemination and natural mating and pilot farmer-feedback systems that assist dairy farmers to improve their productivity are sent via mobile technologies to the farmers. The use of these mobile technologies should be made available, affordable and sustainable to small-scale dairy farmers in other African countries so as to ensure efficiency of information transfer on their cows and herds. In addition, it is essential that all countries in SSA follow InterBull guidelines (InterBull, 2005) for efficient animal recording and data integrity. This will enhance adequate national genetic evaluations for future across-country genetic evaluations. From our study, across-country genetic estimate for AFC was not significantly different from zero for the Jersey breed. Hence predicted genetic gain for this trait based on across-country evaluation was not attainable. Therefore, data integrity within countries must be optimum so as to enhance joint collaborations and joint genetic progress. To further enhance the prospects of an across-country genetic evaluation, it is proposed that countries harmonise methods for data collection to ensure similar formats and trait definitions are applied. This will optimise the accuracy of records and hence, genetic parameters for joint genetic evaluations.

The scope of any breeding programme must be set in relation to the resources available and the stage of development in the countries regions concerned (Boichard and Brochard, 2012). Pooling resources from multiple countries would not only benefit individual programmes as demonstrated in this thesis, but also provide the platform to address genotype by environment interaction in further studies. These breeding strategies must be kept simple and reliable, at least in the first instance, rather than unnecessarily complex and prone to pre-requisites that cannot be guaranteed (Mpofu, 2002; Philipsson, 2000). Breeding strategies would also vary considerably depending on the actual breed, production systems and other circumstances. Therefore, each country should come up with its own needs in relation to production systems. Breeding organisations play a major role in determining what type of dairy cows will populate Africa's dairy farms in the future and the ethical responsibility for the welfare of future populations of cows (Sandøe *et al.,* 1999). Unfortunately, no functioning breeding organisations exist in most countries in sub-Saharan Africa (Chagunda *et al.,* 2013). This is where joint strategies between different countries may be beneficial. Individual countries could benefit from joint genetic evaluations than when these countries have to depend on their national genetic information.

In this thesis, some challenges were faced in terms of poor data quality, lack of international sire identities in pedigree data, poor performance data recording and inadequate handling facilities in these countries. It was difficult to determine sufficient genetic links especially in the Jersey breed. This implied that merging data for joint genetic evaluations was a major challenge. Therefore, in order to overcome these challenges, it is suggested that international animal identities should be kept and made available to joint genetic evaluations. The implementation of defined protocols for data collection across the countries is required. Deliberate efforts should be made by government policy agencies to promote data sharing including relaxation of borders with proper quarantine facilities such that sire semen can be shared across countries. Also major agricultural institutes and universities collaborating across the countries must share expertise, data and scientific knowledge with students and animal science experts.

Genetic parameters and variance components for milk production and reproduction traits varied within- and across the three countries for the breeds studied. Significant variances in milk yield among Holstein-Friesian cattle herds in Kenya has also been reported (Olukoye and Mosi, 2002). Moreover, there are still questions of the possible genotype by environment interaction for the exotic imports especially in terms of the environmental effects considering climate diversity, management and production systems. Also, there is limited or no information on the adaptability, resilience, productivity and disease resistance of the available indigenous breeds currently in Africa's terrains. Furthermore, genetic information on which breeds (exotic and indigenous) or genotypes will thrive well in the environment is limited. The fixed effects of herd of calving, year of calving and season of calving contemporary group used in the models of analysis accounted for management and environmental factors. This may not give promising results in SSA genetic evaluations when compared to temperate regions. Dairy cows tend to move across herds with varying management systems in Africa. Therefore, recording the environment in which the cow is born and where she continues her productive life should be considered as paramount for future genetic evaluations (Mulder *et al.,* 2006). The number of foreign (exotic) sires and cows being used for genetic improvement is increasing annually in SSA and the validity of genetic information for the animals from all countries is increasingly important.

The limited national data structure did not permit national genetic parameter estimation for some traits measured in Chapter 4 and relative response to selection for the same traits in Chapter 5 for Kenya and Zimbabwe. Hence the joint analyses helped in pooling data together and with a country effect included in the model. In general, joint genetic evaluations generated more accurate genetic parameters and breeding values for estimation of genetic progress. The farm at which cows performed had a more important influence on the estimation of genetic parameters.

This may not be a challenge in South Africa as dairy herds are being managed by farmers which adopt the developed countries' method of dairy farming and results in less variation between and among dairy herds.

The predicted relative genetic gain calculated in the present study accounts for selection among males only, and assumes average selection intensity across bull-bull and bull-cow pathways (Rendel and Robertson, 1950; Simm, 1998). The actual rate of gain achieved will depend on the selection intensities and accuracies in each of the four pathways. Typically, over 60% of genetic gain is achieved through sire pathways (Schmidt and Van Vleck, 1974) so scaling the relative responses by 0.6 would give an approximate rate of gain per generation for implementation of optimal breeding strategies that would be sustainable in SSA. However, the contribution of imported cows is a further complication to predicting genetic gain which is ignored in this thesis. When defining breeding goals, new challenges for sustainable production to address societal demands should be considered (Boichard and Brochard, 2012). This is where focus should include milk (fat and protein) yield in conjunction with fertility, health and other functional traits in the breeding goal. As an example, studies propose that multi-trait selection programmes should include health, production, fertility and other welfare traits in breeding objectives (Oltenacu and Broom, 2010; Banga *et al.,* 2014b, Ojango *et al.,* 2017). These traits need to be properly weighted relatively to production traits.

Some key fertility traits in dairy cows are; calving interval, number of services per conception, age at first calving, days open and survival to next lactation (Olori *et al.,* 2002). Calving interval is a primary indicator of a cow's reproductive efficiency (Mujibi *et al.,* 2014). Age at first calving is the time period from cow birth to when she is able to produce her first calf. It determines a cow's ability to produce her first calf. Jamrozik *et al.* (2005) showed that female reproductive traits are affected by genetic and non-genetic factors. Several factors (non-genetic) affecting calving interval are; lactation number, calving season, calving year and management systems being the largest influence in Holstein-Friesian dairy cows (Muller *et al.,* 2014). From our study, reproduction traits (AFC and CI1) in Kenya for both breeds and CI1 in Zimbabwe in Holstein-Friesian were non-estimable. However, benefits were accrued for these traits from across-country evaluations. Fertility traits have been an important issue of interest in genetic evaluations of dairy and beef cattle around the world (Banga *et al.,* 2014a; Berry *et al.,* 2015). Although, genetic correlations between milk production and reproduction traits were not estimable in within-country genetic analyses, they were estimable with reasonable accuracy in across-country genetic analyses. Previous studies have shown that the genetic relationship between production traits (milk yield) and fertility traits are antagonistic (Castillo-Juarez *et al.,* 2000; Haile-Mariam *et al.,* 2003a; Pryce *et al.,* 2004; VanRaden *et al.,* 2004). The genetic correlation between milk production and reproduction traits in Chapter 4 exhibited this antagonism.

A fertile dairy cow is one that shows heat early in the mating period, conceives and maintains pregnancy (Haile-Mariam *et al*., 2003b). Dairy cows with longer calving intervals and higher ages at first calving have tendencies to be more costly to maintain in the herd and therefore result in decreased milk yield, health, metabolic and reproductive problems. From the current study, the Holstein-Friesian and Jersey cows exhibited different intervals between first and second calving and ages at first calving. The main factors affecting AFC and CI1 in small-holder farmers in Africa are; nutrition, disease management systems and effects of season of calving (Dangar and Vataliya, 2014; Mujibi *et al.,* 2014). Cows managed in sub-optimal conditions often have long calving intervals. Many countries around the world have implemented genetic evaluations for female fertility (InterBull, 2005). This is mainly due to increasing concern amongst dairy farmers who are encountering severe reduction in productivity and income due to reproductive failures in their herds (Biffani *et al*., 2005). Therefore, it is necessary to consider traits such as calving interval and age at first calving in selection programmes since these measures of fertility are much easier to collect compared to other measures derived from artificial insemination.

Generation interval remains an important factor to consider in response to selection (Falconer & Mackay, 1996). Abin *et al*. (2016) estimated an average of 6 years for generation interval for five breeds of beef and dairy cattle. Efforts to shorten the generation interval of dairy breeds through genomic technologies have been reported in developed countries with tremendous success (Olson *et al.,* 2012; Hozé *et al.,* 2014) and have been reportedly reduced to 2.5 years (García-Ruiz *et al.,* 2016). For the present study, generation interval was not available for prediction of genetic progress; hence predicted selection responses per generation were derived. Hayes *et al.* (2013) highlighted the importance of genomic selection technologies that are being applied to traits such as milk production in cattle and feed efficiency in chickens, cattle and pigs researches in the developed countries. Rothschild and Plastow (2014) highlighted the need for genomics application to improve livestock in the developing world so as to meet future demands. Genomic selection of reference population with high genetic merits for both milk production and functional (fertility) traits could help in optimising food security in countries in SSA (Van-Marlekoster *et al.,* 2015). In addition more benefits could be achieved if the generation interval of dairy breeds is reduced through genomic selection in SSA. Thus the selective genotyping of key sires used across the various countries could provide the basis of implementing genomic selection in these countries. In the face of advancing genomic technologies in developed countries, obtaining pedigree data in Africa is one of the main problems for genetic evaluations. Therefore, it may be important to use genomic techniques to identify high performing off-springs with or without parentage and its potential use in the future of African dairy genetics.

IMPLICATIONS

Research that led to this PhD thesis contributes to the knowledge needed for optimising dairy production for effective food security in sub-Saharan Africa. Apart from the exciting role of genetics, these improvements would attract other associated benefits. For instance, improved potential in milk yield from genetic selection of proven sires could result in initiatives for improved feeding, management and animal health. This would bring opportunities for improvements in the entire dairy value chain. Dairying has the potential to generate employment and income opportunities to small-holder farmers that constitute the majority in sub-Saharan Africa. Such genetic improvement initiatives have the potential to raise the competitiveness of the small-holder dairy farmers in sub-Saharan Africa dairy development.

GENERAL CONCLUSION

This study has demonstrated the potential and feasibility of joint genetic evaluations for dairy cattle in sub-Saharan Africa. Individual countries included in such genetic improvement programmes will be expected to benefit at varying degrees, depending on their current stage of development with respect to dairy cow performance recording, data processing and within-country genetic evaluation capacity.

RECOMMENDATIONS

In order for the wider dairy sector to benefit from the approaches applied in the present study, there is need for larger datasets including animal records from other African countries. This can be achieved through ensuring efficient data recording and adequate capacity building in individual countries. There must be standard recording systems for performance and pedigree information if routine genetic evaluations were to become available. Countries in sub-Saharan Africa should ensure they use ICAR guidelines for animal recording using international identities and herd book numbers. When traits are not as standard as milk production, then appropriate trait definitions should be harmonised across the countries. This will help in correctly identifying sons and daughters of international sires currently used in Africa. Proper data recording methods will ensure that all sires with daughters in different countries be traced appropriately using their international identities. This will help in pooling data from different countries for implementing across-country genetic evaluations through fitting appropriate statistical models. Pooling data across country could also be a sensitive issue in terms of who has access to these data from other countries. Thus, there is a need for different government bodies in Africa to define a proper and well defined protocol to govern data sharing with adequate confidentiality which is a pre-requite for joint genetic evaluations. As stated earlier, it is highly recommended that the application of a multi-trait model of the InterBull Centre be addressed in future studies for joint genetic evaluations in SSA. An InterBull approach will be beneficial for the future of dairying in Africa. As South Africa holds an InterBull membership since 1999, approaches used for genetic improvements in South Africa can be used as an initial bench-mark for other SSA countries in need of it.

Furthermore, a country like South Africa with more experience in dairy cattle genetic evaluation at the national and international levels, as well as data collection and analysis should take a lead in implementing an initiative for joint genetic evaluations across other countries. In addition to benefiting them in terms of genetic gain, such initiatives will open market opportunities for them. In addition, government officials in these countries should consider joint importation of appropriate genetics for use across the countries and hence enhance the necessary genetic link to underpin joint genetic evaluations. The ability to undertake joint evaluations could encourage breeding companies to test bulls across several countries and hence contribute to enhancing genetic progress in Africa for both foreign and indigenous breeds.

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Appendix 1

Appendix 1 shows the list of themes and questions covered in each theme in the survey. These questions were open-ended, closed-ended, structured, unstructured and combinations of any. This was done to provide as much information on dairy production in respondent's country, their occupation, and what farming systems they were involved in.

Appendix 1: Main themes and lists of questions covered in each theme in the survey.

S/no	Survey themes	Specific questions involved	Open ended	Closed ended	Structured	Unstructured
1	Introduction	- Are you a male or female?		X		
		- In which country are you based?		X	X	
		- What kind of organization do you work with?	X			
		- How will you classify your position?	X			
		- Which livestock production system(s) do you primarily work with?		X	X	
		- What other livestock production systems that is not listed that you associate or work with? (Please specify)	X			X
2	Genetic evaluation methods: data recording systems	- Is there a nationally or regionally coordinated recording system? Yes/No. If No, is there any recording system in place? Please describe. If Yes, what type of data is mainly collected?		X	X	
		- What types of farmers and/or production systems participate in the recording system?		X	X	
		- What types of farmers and/or production systems benefit from the recording system?	X			X
3	Genotypes and breeds	- What dairy breeds are predominantly used for milk production in the country where you work?	X			

4	Dairy policies; dairy improvement infrastructure and capacity	-In the country where you are based, which land tenure system is dairying predominantly practiced?	X			
		- In which production system(s) is dairying predominantly practiced in the country where you are based?		X	X	
		- Dairy crosses (Please specify the breed composition used if possible in the space below)	X			
		- In the country where you are based, how are dairy farmers organized into?	X			X
		- Do you feel the dairy farmers have adequate access to the market for milk?		X		
		- What proportion of milk produced go to; i) Formal market and ii) Informal market?		X		
		- Is there a price difference between formal and informal markets? Higher prices in informal market, higher prices in formal markets or Same price?	X	X		
		- Are there any development policies specifically targeted at dairy production in the country where you are based? Yes/No. If Yes, what are they?	X	X		
5	Challenges facing dairy production	-What are the major challenges facing dairy production in the country where you are based? How can these challenges be alleviated?				X
6	Traits: milk yield levels	- What proportion of milk (%) that is produced in the country where you are based is consumed within the country?	X		X	
7	Genetic evaluations	-Is there a national sire selection/ ranking system? Yes/No. If Yes, please describe? Based on genetic evaluation, Based on phenotypic performance data or other selection criteria (Please describe). If not, has there been any attempt for a national sire selection scheme in the past? Yes/No. If there has been some	X	X		X

		attempts in the past and has been discontinued, could you please describe why these efforts were discontinued?		
8	Future breeding schemes and strategies	- In your opinion, what are the main things that would improve dairy production in the country where you are based? (List them in order of priority starting with the highest)	X	X
9	Future breeding schemes and strategies	-In your opinion, what are the main things that would improve dairy production in the country where you are based? (List them in order of priority starting with the highest)	X	X
		- Would you think that an across-country genetic evaluation scheme would have some mileage in improving dairy production in sub-Saharan Africa? Yes/No. If Yes, please give reasons; If No, give reasons why not?	X	X

Appendix 2

Survey Questions

ACROSS-COUNTRY DAIRY BREEDING STRATEGIES IN SUB-SAHARAN AFRICA
State of existing data and infrastructure in sub-Saharan Africa
As part of a research project in Scotland's Rural College (SRUC) and the Royal (Dick) School of Veterinary Studies (RDSVS) of the University of Edinburgh, we would be very grateful if you would complete this questionnaire. This will take you about 15 minutes. The research aims at examining dairy breeding infrastructure and capacity among small-holder farmers in sub-Saharan Africa.

Q1 Are you a male or female?
Male
Female

Q2 In which country are you based? ....

Q3 What kind of organization do you work with?
Government (Extension)
Government (Research)
University
Non-governmental organisation (NGO)
Private company
Other; Please specify

Q4 How will you classify your position?
Lecturer
Student
Researcher
Development worker
Extension worker
Other; Please specify

Q5a Which livestock production system(s) do you primarily work with?
Pastoral farming
Mixed crop-livestock farming
Subsistence farming
Back-yard farming
Intensive farming
Zero-grazing
Pasture-based farming
Other; Please specify

Q5b What other livestock production systems that is not listed that you associate or work with? (Please specify)
………
………
………
……….

Q6 In the country where you are based, which land tenure system is dairy predominantly practiced?
Communal
Public
Private
Group ownership
Lease-hold
Other; Please specify

Q7 In which production system(s) is dairying predominantly practiced in the country where you are based?
Pastoral farming
Mixed crop-livestock farming
Subsistence farming
Back-yard farming
Intensive farming
Zero-grazing
Pasture-based farming
Other; Please specify

Q8 What dairy breeds are predominantly used for milk production in the country where you work?
………..
………..
………..
………..
…………
………..
Crosses (Please specify the breed composition used if possible in the space below)
…………………………………………………………………………..

Q9a What proportion of milk (%) that is produced in the country where you are based is consumed within the country?

Q9b What happens to the rest of the milk?

Q10 In the country where you are based, how are dairy farmers organized into?
Bulking groups
Cooperatives
Loose groups
Dairy producers' association
Breeding groups
Other; Please specify

Q11a Do you feel the dairy farmers have adequate access to the market for milk?

Yes
No
Q11b What proportion of milk goes to:
i) Formal market …………..
ii) Informal market …………

Q11c Is there a price difference between formal and informal markets? (Please tick)
Higher price in informal market
Higher prices in formal market
Same price

Q12a Is there a nationally or regionally coordinated recording system?
Yes
No

Q12b If No, is there any recording system in place? Please describe

Q12c If Yes, what type of data is mainly collected?
Milk yield data
Reproduction data
Herd health data
Pedigrees
Economic data
Other; Please specify

Q13a What types of farmers and/or production systems participate in the recording system?
Large estates
Pastoral farming
Mixed crop-livestock farming
Subsistence farming
Back-yard farming
Intensive farming
Zero-grazing
Pasture-based farming
Other; Please specify

Q13b What types of farmers and/or production systems benefit from the recording system?
Large estates
Pastoral farming
Mixed crop-livestock farming
Subsistence farming
Back-yard farming
Intensive farming
Zero-grazing
Pasture-based farming
Other; Please specify

Q14a Is there a national sire selection/ ranking system?
Yes
No

Q14b If Yes, please describe
Based on genetic evaluation …………………
Based on phenotypic performance data …………………
Other selection criteria (Please describe) ……………..

Q14c If not, has there been any attempt for a national sire selection scheme in the past?
Yes
No

Q14d If there has been some attempts in the past and has been discontinued, could you please describe why these efforts were discontinued.

Q15 Are there any development policies specifically targeted at dairy production in the country where you are based?
Yes
No
If Yes, what are they?

Q16 In your opinion, what are the main things that would improve dairy production in the country where you are based? (List them in order of priority starting with the highest)

1……………………….
2……………………………
3…………………………..
4……………………………..
5………………………………

Q17a Would you think that an across-country genetic evaluation scheme would have some mileage in improving dairy production in sub-Saharan Africa?
Yes
No

Q17b If Yes, please give reasons

Q17c If No, give reasons why not?

Q18 What big changes do you think would revolutionise dairy production in sub-Saharan Africa?

Q19. In your opinion, what types of traits are the farmers looking for in their dairy cows?

a) For now
b) For the future

Q20 What are the major challenges facing dairy production in the country where you are based?

Q21 How can these challenges be alleviated?

Q22 Are there any other comments/ suggestions that you think could help to improve dairy production in the country where you are based?

Thank You for your time!

Appendix 3: Data structure on current dairy status in respondents' countries and regions in sub-Saharan Africa.

Country	Region	Region codes	No. of Respondents	Females	Males	No. of production systems respondents associate with	Total number of breeds	No. of production system in which dairying is practiced	No. of Exotic breeds	No. of Indigenous breeds	Milk consumed as Liquid (%)	Milk Processed (%)	Milk sold in Formal Markets (%)	Milk sold in Informal Market (%)	No. of land tenure systems for dairying
Burkina Faso	West Africa	5	2	0	2	-	3	-	2	1	40	0	20	80	
Burundi	East African Community	2	2	0	2	4	3	4	1	1	100	0	50	50	1
Cameroon	West Africa	5	3	1	2	4	5	4	1	3	100	0	25	75	2
Ivory Coast	West Africa	5	3	0	3	4	7	5	3	3	55	45	20	80	4
Ethiopia	Eastern Africa	1	3	0	3	1	3	1	2	1	85	15	30	70	2
Gambia	West Africa	5	2	0	2	1	4	1	3	1		0	30	70	1
Kenya	East African Community	2	19	2	17	4	7	4	4	2	89	11	30	70	2
Malawi	Southern Africa	4	3	1	2	3	4	4	2	1	65	35	40	60	2
Nigeria	West Africa	5	13	1	12	2	7	2	2	5	100	0	20	80	4
Senegal	West Africa	5	2	1	1	6	8	6	5	3	100	0	30	70	3
South Africa	Southern Africa	4	6	1	5	4	8	4	7	1	98	2	90	10	2
Sudan	Eastern Africa	3	2	0	2	3	6	3	1	5	20	80	20	20	1
Tanzania	East African Community	2	6	0	6	4	5	4	3	1	90	10	20	80	3
Uganda	East African Community	2	2	0	2	4	3	4	2	1	100	0	70	30	1

Zimbabwe	Southern Africa	4	2	0	2	3	9	3	4	5	65	35	70	30	4

Appendix 4: Summary of data edits for Holstein-Friesian and Jersey breeds from Kenya, South Africa and Zimbabwe.

	Kenya		South Africa		Zimbabwe
	Holstein-Friesian	Jersey	Holstein-Friesian	Jersey	Holstein-Friesian
Number of test-day records in starting dataset	358,327	46,242	-	-	260,747
Number of lactation records in starting dataset	-	-	10,767,516	1,858,021	-
Number of cows in starting dataset	18,868	1,965	377,921	118,255	7,742
Number of cows in edited dataset	10,191	1,123	58,785	99,010	7,714
Number of sires identified in starting dataset	2,617	233	7,397	5,722	285
Number of dams identified in starting dataset	7,849	1,177	135,703	138,890	3,287
Number of calving herds in starting dataset	384	113	1,056	1,150	297
Number of records missing data (including outliers)	8,987	2,131	907,314	1,429,455	25,961
Number of outliers in milk yield	2,450	1,560	70,605	2,590	3,894
Number of records missing	17,867	898	38,316	1,171	1,028

calving dates					
Number of animals missing date of birth	21,734	702	3,368	987	596
Number of animals missing lactation start date	1,543	121	6,981	13,227	1,519
Number of participating calving herds in edited dataset	296	113	1,056	1,009	285
Average test-day milk yield (litres) in edited dataset	17.89±8.39	12.82±7.20	-	-	8.62±3.51
Number of 305-day lactation milk yield records in edited dataset	7, 324	1,189	29,456	67,523	8,191
Average 305-day lactation milk yield (litres) in edited dataset	5,456.45±2,558.95	3,910.10±2,196.01	8,189.34±2,482.21	5,481.24±1,382.61	2,629.10±1,070.55
Maximum number of cows per herd (edited dataset)	61	111	1,814	2,351	111
Minimum number of cows per herd (edited dataset)	1	1	155	299	2
Percentage (%) data lost in edit	99.35	98.06	99.77	96.49	97.72

Over 70% of the records were found in Holstein-Friesian and Jersey breeds present in South Africa, than in Zimbabwe and lowest in Kenya. Proportions of data lost in both breeds in the three countries were over 90%. These were from breakdowns of unedited data that started earlier than 1985 or later than 2014 in the three countries and poor data recording within Kenya and Zimbabwe.

Appendix 5: Predicted genetic gains when candidate sire for selection had a minimum reliability of 30%.

Supplementary Table 1 shows average reliability of Holstein-Friesian sires from within- and across-country (reliability>=0.30). Sire reliabilities were higher for across-country genetic evaluations compared to within-country genetic evaluations.

Supplementary Table 1: Mean reliability of Holstein-Friesian sires within- and across-country (reliability >=0.30).

Traits	Kenya	South Africa	Zimbabwe	Across-country
305-day MY	0.00	0.47	0.45	0.51
305-day first MY	0.00	0.50	0.38	0.51
AFC (days)	0.00	0.52	0.41	0.66
CI1 (days)	0.00	0.36	0.00	0.43

Footnotes: MY (Milk yield), AFC (Age at first calving); CI1 (Interval between first and second calving).

Supplementary Table 2 shows average reliability of Jersey sires within- and across-country (reliability >=0.30).

Supplementary Table 2: Mean reliability of Jersey sires within- and across-country (reliability >=0.30).

Traits	Kenya	South Africa	Across-country
305-day MY	0.00	0.58	0.58
305-day first MY	0.00	0.61	0.61
AFC (days)	0.00	0.00	0.00
CI1 (days)	0.00	0.43	0.44

Supplementary Table 3 shows predicted genetic gains for production traits for Holstein-Friesians from selecting top 5 and 10 sires within- and across-country. Kenya benefited the most from across-country selection (100%) followed by Zimbabwe (54-74%) and South Africa (8-19%).

Supplementary Table 3: Predicted genetic gains (PGG) per generation from sire pathways only for 305-day milk yield (litres) from within- and across-country selection (Holstein-Friesian).

	305-day MY in first lactation (First MY)						305-day milk yield (MY)					
			Top 5 sires		Top 10 sires				Top 5 sires		Top 10 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%	0.00	0.00	0.00	0%	0.00	0%
South Africa	398.77	0.70	734.59	81%	677.98	81%	436.21	0.69	786.98	85%	719.03	92%
Zimbabwe	168.82	0.62	245.48	27%	218.54	26%	255.03	0.67	403.55	44%	359.27	46%
Across-country	450.79	0.72	911.53	100%	841.93	100%	423.07	0.78	926.56	100%	782.53	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

Supplementary Table 4 shows predicted genetic gains for production traits in the Jersey breed. Kenya benefited the most of (100%) than South Africa (4-19%) for production traits.

Supplementary Table 4: Predicted genetic gains (PGG) per generation from sire pathways only for 305-day milk yield (litres) from within- and across-country selection (Jersey).

305-day milk yield (MY)							305-day MY in first lactation (First MY)					
			Top 5 sires		Top 10 sires				Top 5 sires		Top 10 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0.00	0.00	0.00	0.00	0%	0.00	0.00
South Africa	398.77	0.87	965.10	96%	0.87	891.94	436.21	0.81	839.95	90%	0.81	776.27
Across-country	450.79	0.88	1007.71	100%	0.88	928.92	423.07	0.81	928.44	100%	0.81	855.85

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

Supplementary Table 5 shows predicted genetic gain for reproduction traits in Holstein-Friesians from within- and across-country selection.

Supplementary Table 5: Predicted genetic gains (PGG) per generation from sire pathways only for age at first calving (days) and interval between first and second calving (days) from within- and across-country selection (Holstein-Friesian).

Age at first calving (AFC)							Interval between first and second calving (CI1)					
			Top 5 sires		Top 10 sires				Top 5 sires		Top 10 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%	0.00	0.00	0.00	0%	0.00	0%
South Africa	31.76	0.79	65.80	86%	60.12	85%	13.19	0.60	20.82	49%	19.03	48%
Zimbabwe	26.93	0.65	41.16	54%	36.65	52%	0.00	0.00	0.00	0%	0.00	0%
Across-country	37.77	0.72	76.37	100%	70.54	100%	23.06	0.66	42.90	100%	39.62	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.

Supplementary Table 6 shows predicted genetic gains for interval between first and second calving in Jersey breed.

Supplementary Table 6: Predicted genetic gains (PGG) per generation from sire pathways only for interval between first and second calving (days) from within- and across-country selection (Jersey).

Interval between first and second calving (CI1)			Top 5 sires		Top 10 sires	
	Genetic S.D	Accu	PGG	%PGG	PGG	%PGG
Kenya	0.00	0.00	0.00	0%	0.00	0%
South Africa	15.46	0.62	26.74	84%	24.72	84%
Across-country	17.86	0.64	31.88	100%	29.39	100%

Footnotes: Genetic S.D: genetic standard deviation of trait; Accu: square root of reliability; PGG: predicted genetic gain; %PGG: percentage of genetic gain achieved within-country compared to across-country.